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Dispatching System for Control of Combined Sewer Losses

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27 Abstract

Results of initial operation of a computer-based data acquisition and control system for a major urban combined sewer system are presented.

Impressive reductions in combined sewer overflow pollution of the Mississippi River in Minneapolis and St. Paul have been effected. Working entirely within the limits of the existing interceptor sewer system, and with relatively minor modifications to selected major combined sewer regulators, incidence of overflow was reduced by 66% and duration of overflow by 88% during most of a rainfall season. Computer simulation techniques using actual rainfall data indicate that the amount of overflow volume reduction achieved is the equivalent of a $200 million separation project. The reduction in volume of combined overflow to the river is estimated to be between 35% and 70% during the runoff season. The combined sewer system captured about 77% of the urban runoff at the modified locations.

A mathematical model has been developed that will, with rain gage data as input, perform runoff analysis, diversion of combined sewer runoff hydrographs at regulators, and routing of diverted hydrographs through the interceptor system.

Data from rain gages, regulator control devices, trunk sewers and interceptors, and river quality monitors provide real-time operating information. Time variant quality data from key locations in the sewer system have been acquired from analysis of numerous hourly samples. (EPA abstract)

Abstractor Robert L. Callery

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To be continued on inside back cover

DISPATCHING SYSTEM FOR CONTROL OF COMBINED SEWER LOSSES

by
Minneapolis-Saint Paul Sanitary District
now the
Metropolitan Sewer Board
St. Paul, Minnesota

For the
Environmental Protection Agency
Water Quality Office

Demonstration Grant 11020 FAQ
March, 1971

NOTE: On August 1, 1970, the Minneapolis-Saint Paul Sanitary District was absorbed by the Metropolitan Sewer Board. The Metropolitan Sewer Board carries on all functions of the former Sanitary District.

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ABSTRACT

Impressive reductions in combined sewer overflow pollution of the Mississippi River in Minneapolis and Saint Paul have been effected by a regulator control system. Working entirely within the limits of the existing interceptor sewer system, and with relatively minor modifications to selected major combined sewer regulators, incidence of overflow was reduced by 66% and duration of overflow by 88% during most of a rainfall season. Computer simulation techniques using actual rainfall data indicate that the amount of overflow volume reduction achieved is the equivalent of a $200 million separation project. The efficiency of collection was improved by about 20% at controlled regulators. The reduction in volume of combined overflow to the river is estimated to be between 35% and 70% during the runoff season. The unmodified combined sewer system captured about 65% of the urban runoff. Where modified, the system captured about 77% of the urban runoff.

A mathematical model has been prepared that will, with rain gage data as input, perform rainfall runoff analysis, diversion of combined sewer runoff hydrographs at regulators, and routing of diverted hydrographs through the interceptor system. This model will assist in operation of the system to retain combined sewer flows and utilize the maximum flow capacity of the existing interceptor sewer system. Part II of this report describes the model.

The 1.75 million dollar project includes a computer-based data acquisition and control system that permits remote control of modified combined sewage regulators. Data from rain gages, regulator control devices, trunk sewers and interceptors, and river quality monitors provide real-time operating information. Time varient quality data from key locations in the sewer system were obtained by automated analysis of numerous hourly samples.

Work on the "Dispatching System for Control of Combined Sewer Losses" began in 1966, and the system has been operated since April, 1969.

This report was submitted in fulfillment of Demonstration Grant 11020 FAQ, supported in part by the Environmental Protection Agency, Water Quality Office.

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I. Summary, Findings and Conclusions

Summary

This project was conceived during the period between 1956 and 1960 when the sewer and interceptor systems of Minneapolis and Saint Paul were intensively investigated as part of a study for the Minneapolis–Saint Paul Sanitary District on "Expansion of Sewage Works in the Minneapolis-Saint Paul Metropolitan Area." These investigations revealed that the interceptor system was not being fully utilized for conveyance of combined sewage during periods of rainfall and runoff. The net effect of the multiple regulator settings all over the Twin Cities was that combined sewage was often needlessly diverted to the Mississippi River when interceptor capacity was available. Moreover, the studies revealed that rainfall seldom, if ever, occurs uniformly over the Twin Cities and that this rainfall diversity could be used to advantage in reducing or eliminating combined sewage overflows if a means of controlling a variable diversion regulator were available.

In 1965 the Minneapolis-Saint Paul Sanitary District took over the responsibility for maintenance and operation of combined sewage regulators in Minneapolis and Saint Paul from their respective Sewer Departments in an effort to improve the performance of the regulators and reduce combined sewer overflow pollution by more intensive monitoring. A special Regulator Crew was organized and equipped for this purpose.

After legislation in the Water Quality Act of 1965 provided the possibility of obtaining Federal funding assistance, the Minneapolis-Saint Paul Sanitary District was prepared and made an application to the Federal Water Pollution Administration for a "Facilities Demonstration Grant" to demonstrate an improved method for controlling the discharge from a sewer system carrying storm water and sewage. This application was accepted in April, 1966, and the Minneapolis-Saint Paul Sanitary District obtained the first of the FWPCA Demonstration Grants, a sum of $870,750, to constitute 50% funding for a "Dispatching System for Control of Combined Sewer Losses." The project was described in the application as follows:

> *"The Cities of Minneapolis and Saint Paul are generally served by combined sewer systems. Overflows from the sewer system to the Mississippi River, caused by rainfall or thaw, occur at more than 150 points in the system. The losses of domestic and industrial wastewater are estimated to be up to six per cent of the annual wastewater flow and possibly from six to fifteen per cent of the annual average solids and BOD. The losses occur mainly in the spring, summer and fall. No assessment of the effect of overflows on the bacterial condition of the river has been made.*
>
> *The proposed system envisions extensive modifications to diversion structures at approximately 15 points along the interceptor system, minor modifications at most of the remaining diversions, and construction of five new 'Master Diversions' at key interceptors, along with telemetry and supervisory control systems to allow monitoring of overflow interceptor utilization. Maximum utilization of the interceptor system and treatment facilities will then be possible, considering rainfall distribution and other factors. The routing or dispatching of mixed storm and wastewater flows can be controlled based on locations of storms in the system, time of day and other factors. At diversions with high pollutional load, priority can be given to avoiding losses during run-off. The fifteen diversions carried approximately 80 per cent of the Sanitary District's load in 1960.*
>
> *Past estimates of the cost of separation of all sewer systems in both cities have ranged from $30,000,000 for a low degree of separation to $100,000,000[1] for fairly complete separation which precludes such a program in the near future. The proposed system will considerably reduce losses at a nominal cost.*
>
> *The pre-construction and post-construction evaluation will take full advantage of modern data handling and analysis techniques with development of correlations, time series analysis and mathematical models. All data will be in accordance with the USPHS "STORET" system to facilitate use of data by other agencies. Real time data processing techniques will be used to direct the operation of the system, demonstrating its use in the field of pollution abatement, and providing useful data for future planning and operations of the proposed system or those which might be designed for other areas for reduction of combined sewer system losses.*
>
> *The proposed project will demonstrate a new technique of instantaneous observation and control of interceptor system performance based on adequate information to drastically reduce losses of combined wastes. Information gathered in operation of the system will provide a basis for further reduction of losses by using trunk sewers for storage and the facilities constructed will allow such a measure to be attempted. Post-construction evaluation will provide information which will allow the method to be adapted to other large combined sewer systems of differing configuration and climatology.*
>
> *Since the majority of losses of wastes occurs during the recreational season, considerable benefit to the Mississippi River, where it passes through the populated area, will accrue."*

---

[1] More recent estimates place the cost for complete separation at $600,000,000.

The first year of the project was spent in preparation of plans and specifications for the major contracts involved in the project. Preliminary in-sewer work for the gaging system was also done by Sanitary District personnel. Construction phases of the project began in 1967 and Regulator Modifications were completed in 1968.

Figure 1 shows, on a map of the metropolitan area all the elements of the system, including the existing interceptors. There are 18 control and monitoring stations on the regulator-interceptor system, nine monitoring rain gages and five river quality monitors.

Most components of the regulator control and monitoring system are shown in Figure 2, an artist's rendition of a regulator typical of those that were modified. The underground vault provides a suitable location for all the electronic and motorized equipment which is connected to electric power and telephone circuits. Depth of flow is measured upstream from the diversion dam and downstream from the regulator gate in the outlet pipe leading to the interceptor. The gate is operated by an operating cylinder and an oil hydraulic power system in the vault and can be remotely controlled. The diversion dam is inflated with air and can also be remotely controlled. Water can flow over the inflated dam, which does not completely close off the trunk sewer. The dam can be deflated to afford almost full hydraulic capacity of the pipe.

The central control station for the system is located in the Administration Building at the Minneapolis-Saint Paul Sanitary District Wastewater Treatment Plant. The central part of the system is the process control equipment, the functional parts of which are shown on Figure 3. The same type of equipment has been used to control electric power systems, refineries, chemical plants, steel mills and many other processes. In addition to accomplishing control and monitoring of the outplant system, the system is capable of logging treatment plant operating data.

Findings and Conclusions

Real operation of the system began in April, 1969. During the 1969 runoff season operation was somewhat impeded by a major flood on the Mississippi River and later by "hardware bugs" that prevented complete acquisition of data. Additionally, the rainfall occurring during 1969 was considerably less than normal. Nevertheless, enough data that could be used for purposes of evaluation was accumulated. More recent data from April and May, 1970, supplements that from the initial operating season.

The data collected from each regulator allows one to determine when the depth of flow exceeds the height of the Fabridam or any other height, such as the height of the fixed weir that was replaced by the Fabridam. Based upon the actual data, tables showing performance as measured by reduction in incidence of overflow and by reduction in duration of overflow were prepared. Incidence and duration of overflow were determined for pre-project conditions with fixed height diversion weirs and post-project conditions with fully inflated Fabridams as the diversion weirs.

The results of these analyses are summarized in Table 1.

Table 1

REDUCTION IN INCIDENCE AND DURATION OF REGULATOR OVERFLOWS ACCOMPLISHED BY REGULATOR DEMONSTRATION PROGRAM

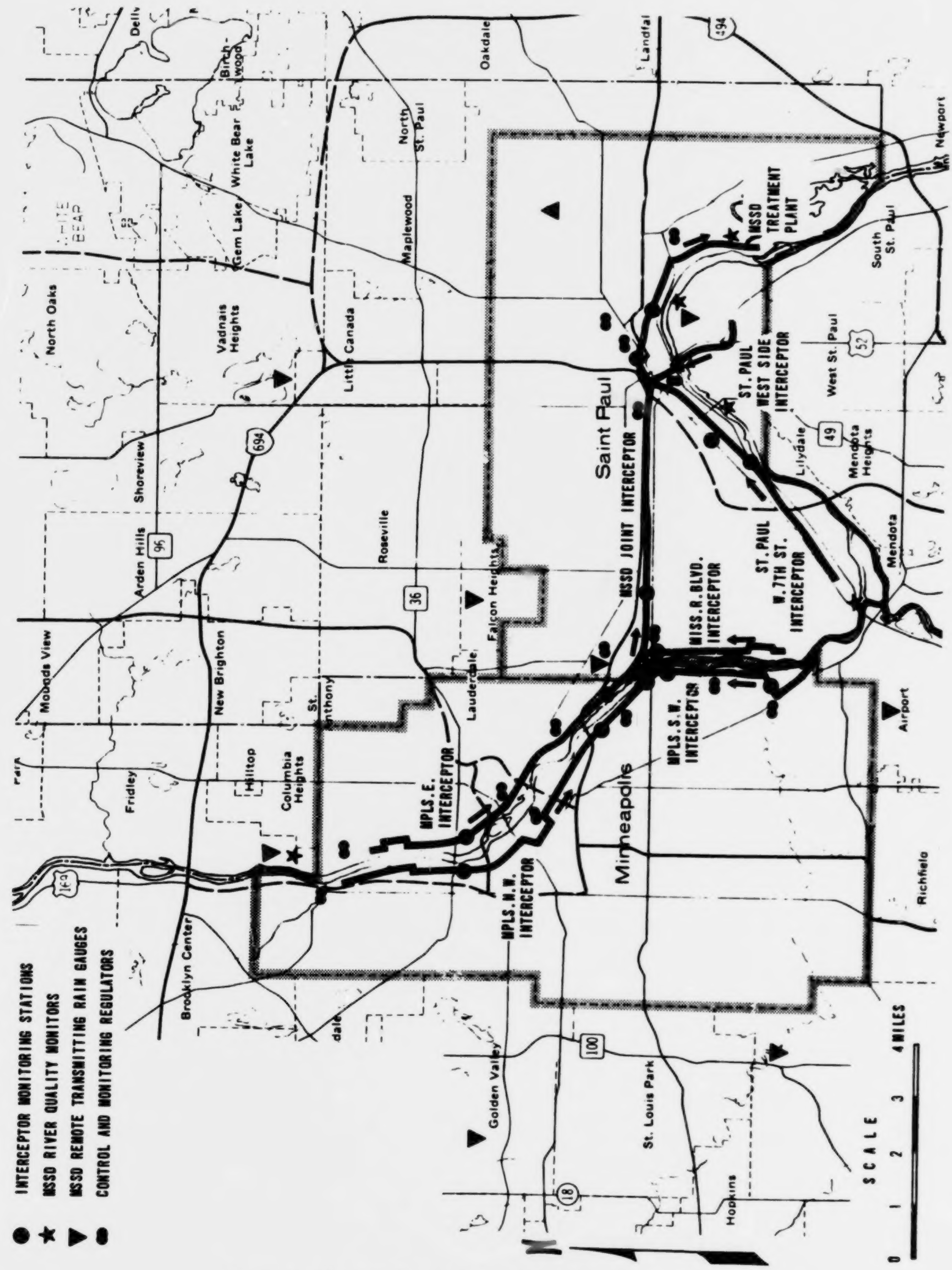
	% Reduction in Incidence	% Reduction in Duration
16 1969 Rains.	65	88
11 1970 Rains (April and May)	49	87
Total of 27 Rains.	58	88

A reduction of incidence, obviously, could only be accomplished when the modifications at the regulator, primarily the Fabridam, allowed complete retention or diversion of combined sewer runoff that would not have been possible with the old fixed weirs. Reductions in duration were calculated by comparing total regulator hours of duration for the two cases. The duration figures are high primarily because many of the old weirs were set only slightly higher than dry weather flow, and consequently the trailing or falling limb of the storm hydrograph would cause overflow for several hours after the bulk of the storm water had passed. Interpretation was used to prevent distortion of duration data that could be caused, and usually a depth flow within a few inches of the weir height was used as the point of overflow cessation.

For purposes of evaluating performance, 16 rainfall events were selected from the 1969 rainfall season. Although more rains occurred during the 1969 rainfall season, the monitoring system did not acquire data on all of them, and some data that was gathered was lost. Particularly troublesome were hardware problems in the disk handler which were completely corrected on July 10, 1969.

The 16 selected rains do provide a representative sampling, since they include 56 per cent of the rainfall which occurred during the period between April 26 and November 16.

This 1969 data was supplemented by data from eleven rains occurring in April and May of 1970. When the 27 means of total rainfall at each of the system gages are added, the sum is 15.59 inches, so the data sample analyzed is almost equivalent to a normal rainfall season, at least as measured by precipitation.


● INTERCEPTOR MONITORING STATIONS
★ MSSD RIVER QUALITY MONITORS
▶ MSSD REMOTE TRANSMITTING RAIN GAUGES
● CONTROL AND MONITORING REGULATORS
SCALE
0 1 2 3 4 MILES
MPLS. N.W. INTERCEPTOR
MPLS. E. INTERCEPTOR
MPLS. S.W. INTERCEPTOR
MISS. R. BLVD. INTERCEPTOR
MSSD JOINT INTERCEPTOR
ST. PAUL W. 7TH ST. INTERCEPTOR
ST. PAUL WEST SIDE INTERCEPTOR
MSSD TREATMENT PLANT
Minneapolis
Saint Paul
Brooklyn Center
Fridley
Columbia Heights
Hilltop
St. Anthony
New Brighton
Mounds View
Arden Hills
Shoreview
North Oaks
Vadnais Heights
Gem Lake
White Bear Lake
Birchwood
Little Canada
Roseville
Lauderdale
Falcon Heights
Maplewood
North St. Paul
Oakdale
Landfall
Newport
South St. Paul
West St. Paul
Lilydale
Mendota Heights
Mendota
Airport
Richfield
Golden Valley
St. Louis Park
Hopkins
694
96
36
100
18
49
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494
169

Figure 1. Minneapolis St. Paul Control and Monitoring System

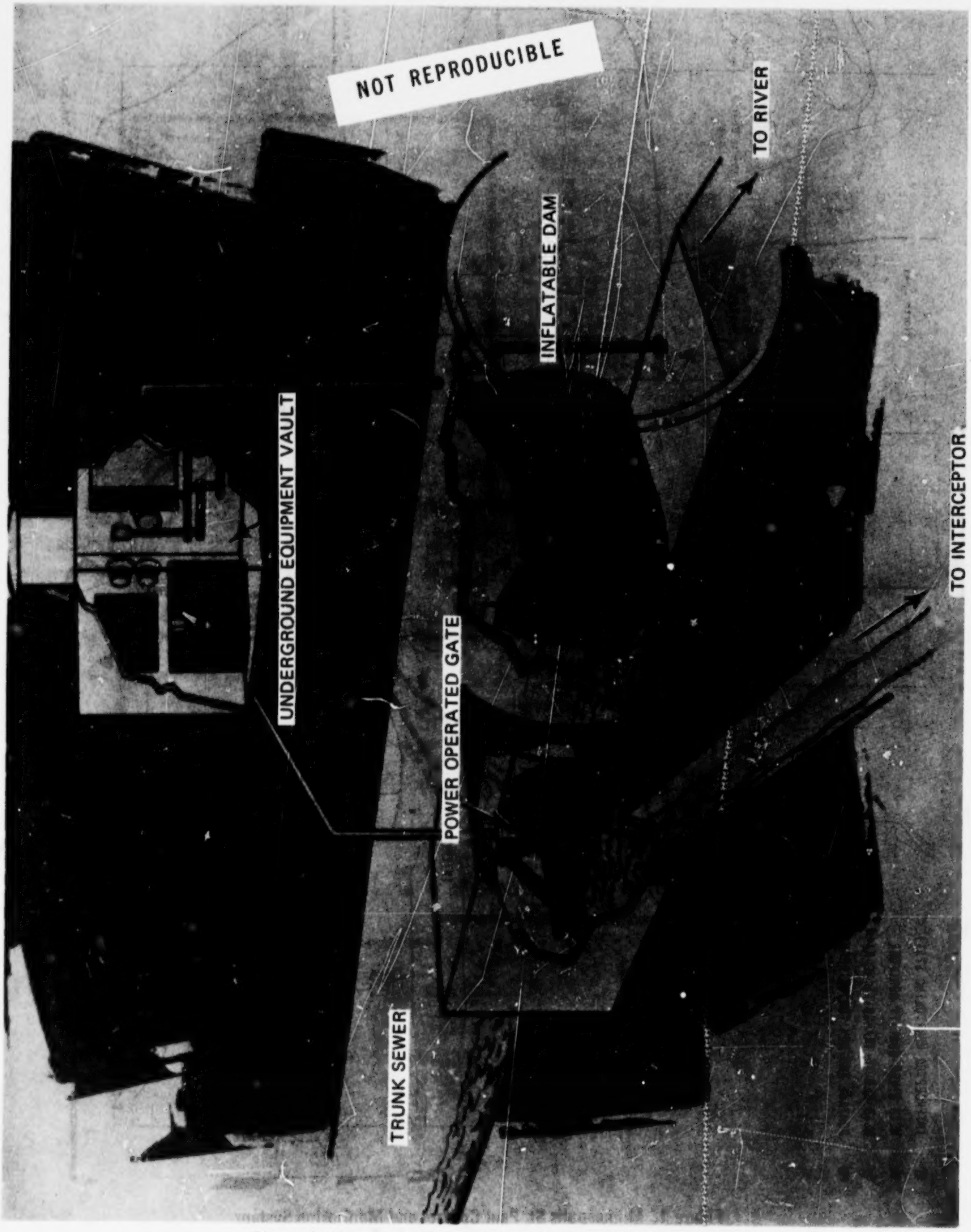
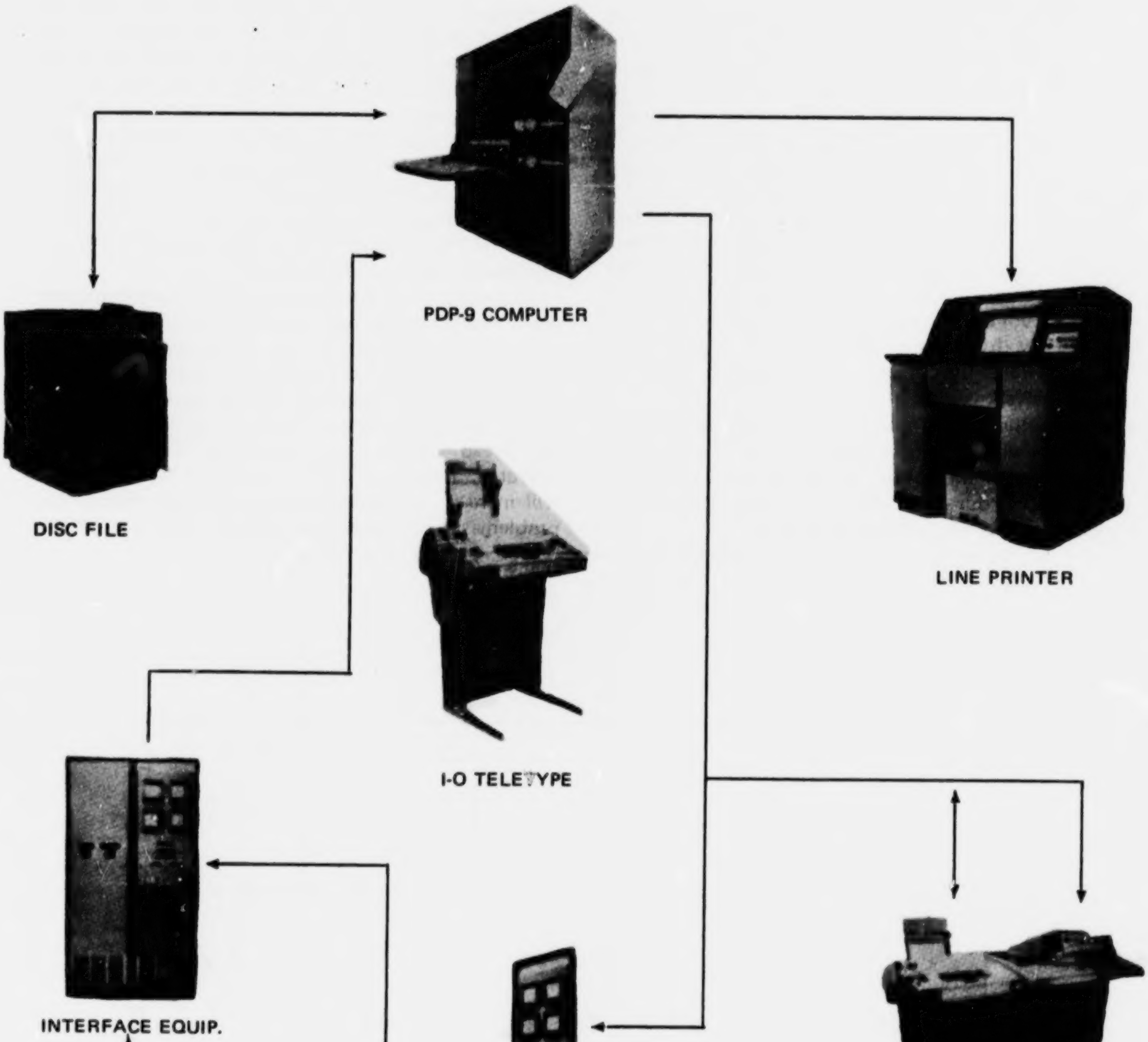

NOT REPRODUCIBLE
TO RIVER
INFLATABLE DAM
UNDERGROUND EQUIPMENT VAULT
TO INTERCEPTOR
POWER OPERATED GATE
TRUNK SEWER

Figure 2. Drawing of Typical Control and Monitoring Regulator


PDP-9 COMPUTER
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I-O TELETYPE
INTERFACE EQUIP.
7 LEASED LINES FROM OUTPLANT STATIONS
TREND RECORDERS AND OPERATORS PANEL
OPERATORS AND LOGGING TELETYPES
PLANT CONTROL ROOM

The central part of the system is the process control equipment. The same type of equipment has been used to control electric power systems, refineries, chemical plants, steel mills and many other processes. This system can control the sewer system and has also been designed to take readings of treatment plant performance.

Figure 3. Central Station Process Control Equipment

Although these analyses certainly indicate that the control system has great potential and has improved the capture efficiency of the combined sewer-regulator-interceptor system, it is desirable to be able to speak in terms of overflow volume kept out of the river by the system and still entering the river during large storms in spite of the system. The mathematical model of the sewer-regulator-interceptor system provided a convenient method of simulating pre- and post-project conditions and was used with data from certain rain days to calculate reduction in volume of overflow occuring from the operation of the system. Total overflow volumes from 11 major regulators were reduced by from 98 to 30 per cent during seven individual rains by operation of the system according to this analysis.

The mathematical model was also used with simulated rainfall data in an attempt to evaluate the effectiveness of the control system in terms of rainfall intensity and duration. Figure 4 shows how rainfall intensity effects regulator performance.

Analysis of interceptor monitoring data indicates that full capacity of the Minneapolis Southwest and East Interceptors has been utilized on several occasions during rainstorms. The capacities of the Minneapolis Northwest and Joint Interceptors are being utilized much more fully than in 1960 when previous gaging data was collected. Evidence suggests that the Joint Interceptor at the treatment plant has been operated at near full capacity on several occasions. Figure 5 compares the utilizations of the Minneapolis Northwest Interceptor during 1969 and 1960.

A system for controlling overflows from combined sewer regulators has been installed and operated. Very significant reductions in combined sewer overflows have been effected and documented through use of this control and data acquisition system since the spring of 1969. Overflow control benefits will continue to accrue so long as the system is maintained and operated. Moreover, the effectiveness of the system will increase as operating experience accumulates and problems encountered are solved. The use of the

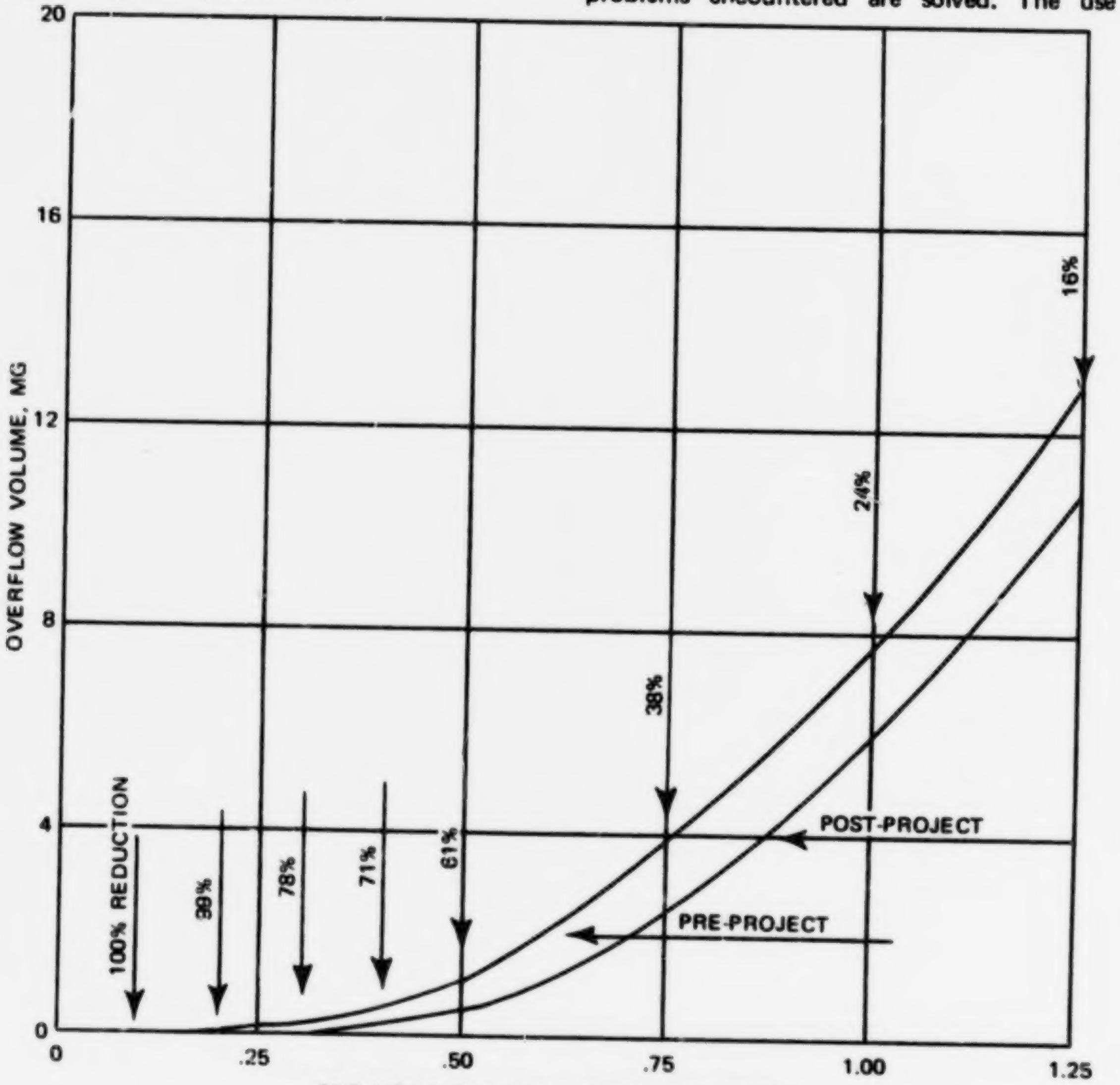

Figure 4. Performance of Modified Regulators for Simulated One Hour Rains

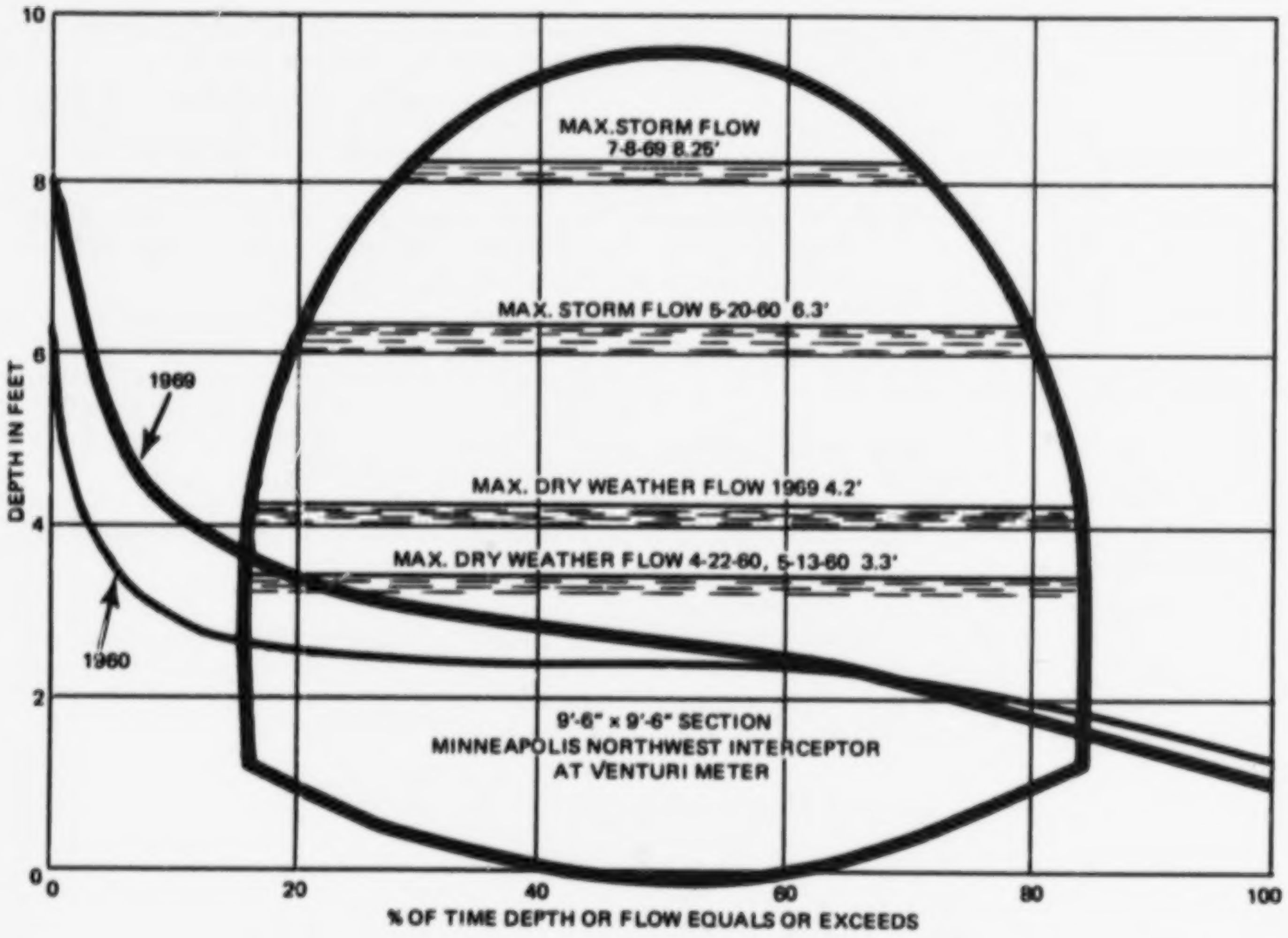

Figure 5. Utilization of Minneapolis Northwest Interceptor—1960 and 1969

operating rainfall-runoff-diversion-routing mathematical model developed for the system when available as a real-time operating aid, will also increase the effectiveness of the overall system.

Data acquisition and operating experience will make it possible to up-date, improve, and even expand the existing mathematical model. A logical extension of the model, incorporation of flow data feedback, is discussed in Part II of this report.

The overall flexibility of the computer based system will permit operation to meet changing conditions in the tributary urban area. The data acquired by the system will be of great value in planning future modifications of the existing combined sewer and interceptor system. The mathematical model can be modified and used to test and evaluate new ideas and alternative solutions to various problems related to the combined sewer system and the interceptor system.

Considering the present concern about the polluting effect of separate storm sewer discharges and the increasing body of evidence supporting this concern, this system has had an effect on the magnitude of storm related pollution greater than that which would occur from a 200 million dollar sewer separation program which would require years to complete.

Among the accomplishments and findings of this project can be listed the following:

1. The number of regulator overflow occurrences at controlled regulators was reduced by 58 per cent. In 27 rainfall events 164 overflow discharges were prevented.

2. The total combined sewer overflow hours at controlled regulators were reduced by 88 per cent. In 27 rainfall events 1036 overflow hours were prevented.

3. In 7 rainfall events analyzed for overflow volume at 11 controlled regulators, overflow volumes for individual rains were reduced by from 98 to 30 per cent, with a net reduction of 51 per cent. Except for intense storms occurring only two or three times per year, overflow volumes at these regulators can be reduced by about 75 per cent or more.

4. Estimates place the total annual overflow volume that can be saved by the system at 230 MG. To duplicate this reduction by a separation program,

10,000 combined sewered acres would have to be separated at a probable cost of at least 200 million dollars.

5. Data acquisition and computer analysis indicate that the runoff capture efficiency of the combined sewer system was improved by about 20 per cent at controlled regulators. The reduction in volume of combined overflow to the river is estimated to be between 35 per cent and 70 per cent during the runoff season. The unmodified combined sewer system captured about 65 per cent of the urban runoff. The modified system captured 77 per cent of urban runoff at the modified locations.

6. A network of nine telemetering rain gages have and are providing urban rainfall information of a quantity and quality never before available. Rainfall diversity over the metropolitan area has been shown to be very common.

7. Monitoring of the existing interceptor system has shown that it is now being more effectively utilized for conveying storm water runoff.

8. River quality monitors along the urban reaches of the Mississippi River have shown that the physical quality of the water is not appreciably affected by storm and combined sewer discharges.

9. Analysis of sewage at many points in the sewer system has permitted the establishment of diversion priorities to help reduce combined sewer overflow pollution.

10. The control system was shown to have practically eliminated overflow from spring thaw runoff at the controlled regulators.

11. A working, verified, and calibrated mathematical model of the urban hydrology and the combined sewer regulator-interceptor system has been prepared and is available for studies and as a sewer system operating aid. This model is thoroughly described in Part II of this report.

12. The regulator monitoring system has permitted continuous surveillance of the major combined sewer regulators.

13. The program has demonstrated the efficacy and value of a computer basec control and monitoring system for overall efficiency of data acquisition and control and monitoring functions.

II. INTRODUCTION

Minneapolis-St. Paul Climatology, River System, and Sewer System.

Minneapolis and St. Paul, commonly known as the Twin Cities, are located side by side along the Mississippi River in Eastern Minnesota. The climate is temperate, with temperature ranges between extremes of 99°F and −32°F. Climatological standard normal (1931-60) precipitation is 24.78 inches annually. Of this, 16.07 occurs during the months May through September. Table 2 shows the maximum, normal, and minimum precipitation in Minneapolis-St. Paul for each month.

A recent publication by the University of Minnesota (1) indicates that series of annual precipitation amounts are approximately normally distributed. In this report a somewhat longer period of record was studied for Minneapolis-St. Paul than the climatological standard period, 1931-60. St. Paul data from 1837 to 1933 and Minneapolis data from 1934 to 1965 provided a combined 129 year record. The range in annual total precipitation is great, 39.48 inches, between a maximum of 49.69 inches in 1849 and a minimum of 10.21 inches in 1910. The 129 year mean annual precipitation is 26.85 inches.

The Mississippi River enters the Twin Cities from the North 1812 miles above its mouth. The river approximately bisects the Metropolitan area, flowing within, between, or along Minneapolis or St. Paul for 25 miles. The Minnesota River flows into the Mississippi River near the middle of its urban reach at River Mile 1799. Lock and Dam No. 1 on the Mississippi River is about two miles upstream from the Minnesota River confluence. The Mississippi River watershed is about 16,000 square miles. The corps of Engineers maintains a 9 ft. navigation channel in the river, with the head of navigation being located in the upper St. Anthony Pool at River Mile 1811.

Upstream from St. Anthony Falls, the Mississippi River flows through primarily glacial drift. Downstream from St. Anthony Falls, the River flows through a narrow gorge for about 10 miles. Below the Minnesota River confluence, the Mississippi occupies a portion of a wider valley formed by a large pre-glacial river.

Table 3 and Table 4 summarize USGS river data for the Mississippi River and Minnesota River. Minnesota River near Carver is 36 miles upstream from the Mississippi River. Mississippi River near Anoka is about 6 miles upstream from Minneapolis. Mississippi River at St. Paul is about 6 miles downstream from the Minnesota River.

Table 2

MINNEAPOLIS – SAINT PAUL PRECIPITATION (1931 – 1960)

MINNEAPOLIS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	1.65	2.66	3.37	3.53	7.87	7.80	7.10	6.60	7.53	5.64	5.15	1.99
Normal	0.70	0.78	1.53	1.85	3.19	4.00	3.27	3.18	2.43	1.59	1.40	0.86
Minimum	0.11	0.14	0.48	0.62	0.74	1.26	0.11	0.43	0.41	0.26	0.27	0.06

Table 3

USGS DATA FOR MISSISSIPPI AND MINNESOTA RIVERS THROUGH WATER YEAR 1966

	Mississippi River Near Anoka	Minnesota River Near Carver	Mississippi River at St. Paul
Drainage area, sq. mi.	19,100	16,200	36,800
Period of record, years	35	32	68
Period of record mean day, cfs	7,053	3,174	10,080
Period of record maximum day, cfs	91,000	117,000	171,000
Period of record minimum day, cfs	586	79	632

Table 4
MINIMUM, MEAN AND MAXIMUM RIVER FLOWS, CFS

Calendar Year	Mississippi River Near Anoka			Minnesota River Near Carver			Mississippi River at St. Paul		
	Min.	Mean	Max.	Min.	Mean.	Max.	Min.	Mean	Max.
1962	1700	8232	39400	350	6028	39400	2020	14590	56200
1963	1750	5854	22100	390	2760	14400	2370	8546	31300
1964	1820	5856	23700	385	2080	12900	2170	7820	32300
1965	2900	13730	90300	372	7782	112000	3410	22380	171000
1966	2200	11800	42200	482	3336	16000	2260	15730	52200
1967	1500	7500	40600	245	3381	19300	1950	11100	52100
1968	1500	7700	20600	185	4217	37200	1750	12400	25500

Minneapolis, St. Paul, and most of their suburbs are served by a single large waste water treatment plant operated by the Minneapolis-Saint Paul Sanitary District (MSSD). The extensive interceptor system leading to a single large treatment plant was feasible because of favorable topographic and geological conditions. Ground elevations in the entire region served permit the use of gravity flow. A sandstone formation underlying much of the area permitted the construction of large interceptor sewers by economical tunneling methods. With the favorable ground elevations and the deep interceptors, very little pumping is required. The total area served is 144,000 acres, of which 54,000 acres are in the core cities of Minneapolis and St. Paul. Total estimated tributary population is 1,400,000, with a population equivalent based on BOD of approximately 2,400,000. Interceptor sewers were constructed during 1934-1938 by Minneapolis, St. Paul, and the MSSD. Figure 6 identifies the major existing interceptor sewers. Flow from the three Minneapolis Interceptors is metered primarily for purposes of cost apportionment.

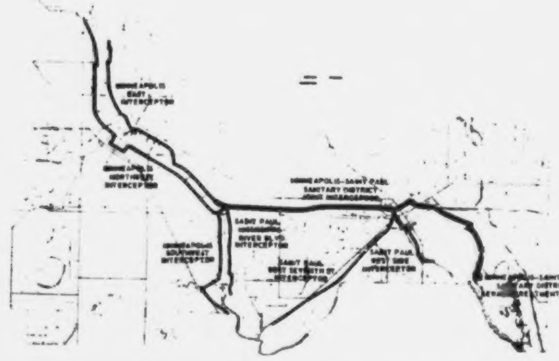
MINNEAPOLIS EAST INTERCEPTOR
MINNEAPOLIS NORTHWEST INTERCEPTOR
MINNEAPOLIS-SAINT PAUL SANITARY DISTRICT JOINT INTERCEPTOR
SAINT PAUL RIVER BLVD. INTERCEPTOR
MINNEAPOLIS SOUTHWEST INTERCEPTOR
SAINT PAUL WEST SEVENTH ST. INTERCEPTOR
SAINT PAUL WEST SIDE INTERCEPTOR
MINNEAPOLIS-SAINT PAUL SANITARY DISTRICT TREATMENT PLANT

Figure 6. Routes of the Principal Intercepting Sewers

Table 5 indicates the section and capacity of the interceptors at their downstream ends. Twenty-eight miles of branch interceptors were constructed by the two Cities, and a nine mile jointly used interceptor was constructed by the MSSD. The replacement cost of this interceptor system is in excess of $100 million, with the replacement cost of the Joint Interceptor alone in excess of $25 million.

Table 5
INTERCEPTORS IN MINNEAPOLIS AND SAINT PAUL

Interceptor	Section	Capacity, MGD
Minneapolis NW	9'6" x 9'6"	230
Minneapolis SW	6'0" x 6'0"	75
Minneapolis E	6'0" x 6'0"	85
Miss. River Blvd.	3'9" x 5'10"	40
W. 7th St.	5'0" x 6'0"	56
West Side	3'6" x 5'6"	34
Joint	9'6" x 10'0" Double Barrel	620

The system was designed to provide for the sewage flow for the year 1970 from a population of 1,400,000. Design capacity for the interceptors was calculated at 55 percent for sanitary sewage and 45 percent for storm flow.

Sewage regulators accomplish the diversion of flow from trunk sewers into the interceptor system. They also control or limit the quantity of combined sewage which enters the interceptor during periods of runoff. About 150 separate regulators and diversion structures are used in the two cities. The regulators are of various types, float operated gates, tipping gates, orifices, leaping weirs, and simple diversions. The original design of the regulators was intended to allow some storm water to enter the interceptor system. The 1928 Report of the Metropolitan Drainage Commission describes this "first-flush" of storm water as that quantity assumed to be caused by a rainfall intensity of 0.04 inches per hour. The rate of runoff was determined by the Rational Method with assumed coefficients ranging from 0.2 to 0.8.

Most suburbs are served by separate sewer systems but discharge into either combined sewers or interceptor sewers which carry combined flow.

Minneapolis has carried on a program of sewer separation since 1933. Separation is limited to street catch basins and is not, however, 100% effective. The separation work has been accelerated during the past 10 years and is being continued. As of 1969 the city is nominally 75% separated, that is served to some extent by separate storm drainage. Saint Paul is still primarily served by combined sewers, with only about 20% of its sewered area served by a separate sewer system.

Minneapolis-Saint Paul Sewage Works Studies, 1956-1961

In May 1956, the Board of Trustees of the Minneapolis-Saint Paul Sanitary District authorized a five year program of research and development on future metropolitan area sewage works needs. Because the existing interceptor system would certainly be utilized as the backbone of a future expanded system, engineering investigation was undertaken to determine its current utilization. A gaging program accumulated flow depth data at 12 locations during parts of 1958, 1959, and 1960 to supplement the flow records available from meter stations on the Minneapolis Interceptors and at the Treatment Plant. Data was also obtained from about 20 non-recording rain gages read daily by volunteer observers. Frequency distributions of recorded flow depths were made and maximum flow depths during dry weather flow periods and during storm flow periods were noted.

Figure 7 shows a cumulative frequency distribution or ogive for the Joint Interceptor at Third St. and

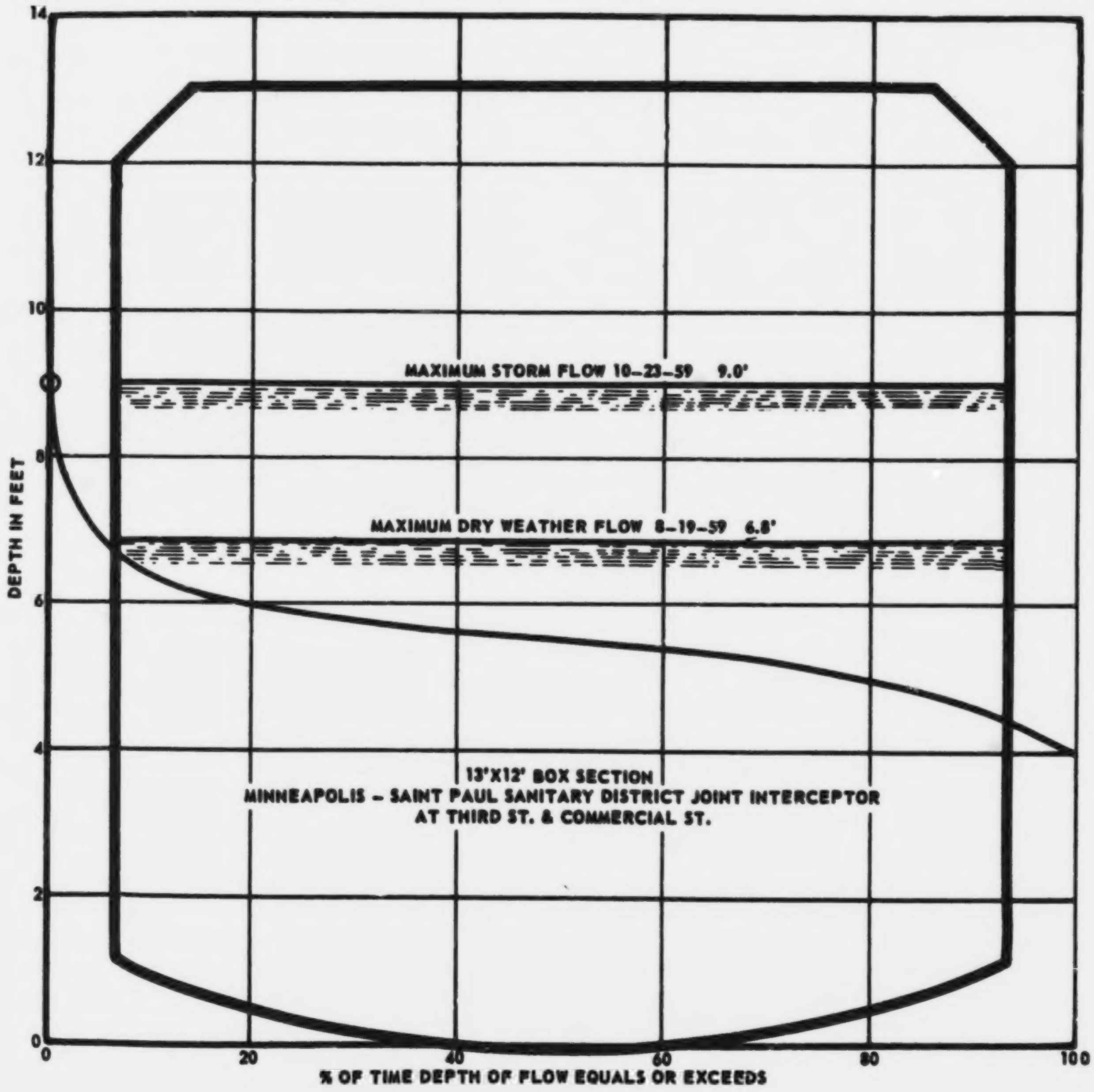

Figure 7. Utilization of Joint Interceptor

Commercial St. in St. Paul. This location is about 2.4 miles upstream from the Treatment Plant, and only a few inlets to the Joint Interceptor are downstream from it. That storm flow conditions occur only a small percentage of time is evident from the figure. The volume of storm water flowing in the interceptor during this small percentage of time is dependent upon the amount of rain and the functioning of sewage regulators. At this location and at others in the interceptor system it was found that the capacity of the pipe was far from being fully utilized even during heavy rainstorms.

As part of the studies an inspection was made of each regulator in the system. About 120 regulators consisting of float operated gates, tipping gates, orifices, leaping weirs, and simple diversions were known to be in use at that time. Many were of relatively small size, on 10 inch and smaller sewers. In general it was found that the regulators were not functioning as originally planned. The original design was usually not conducive to regular maintenance so non-functioning mechanical devices and obstructed openings were found. Changing flow conditions and operational problems had also necessitated modifications at some regulators. In both cities some regulators were found to be permitting overflow to the River during dry weather. Poor hydraulic flow conditions, where velocities and turbulence were great, caused some of these instances. Other regulators were found to be operating under flow conditions where only a very small amount of storm flow would initiate overflow. The net effect of all the regulator operating conditions was such that the interceptors seldom or never operated at full capacity. Conveying capacity available for storm flow was unused at the same time that overflows would be occurring at many regulators.

It was determined that 15 major regulators diverted an estimated 80 percent of the total dry weather flow arriving at the Treatment Plant. These large regulators were also the ones causing most problems and at which most combined sewer losses occurred. The structures at the metering stations at the ends of the three Minneapolis Interceptors also act somewhat as regulators, since the interceptor can be relieved to the river by overflow weirs and bypass gates. These 15 regulators and 3 interceptor metering stations were recognized as 18 key locations for effecting control of combined sewer losses.

Another recommendation of the report was that "All regulators which are adjacent to interceptors should be placed under the control of a single authority since they play the most important role in controlling interceptor use and overflows affecting the river. In addition to permitting readjustment of all regulators to optimum settings, central control would also assist in preventing unnecessary by-passing of raw sewage, thereby improving river conditions within the Cities."

In 1965 Minneapolis and St. Paul enacted ordinances which transferred to the Sanitary District the control of and responsibility for the operation and maintenance of combined storm and sanitary sewer diversions and regulators from which overflow can be conveyed directly into the Mississippi River. A regulator crew was established by the Sanitary District to carry out this newly assigned responsibility. The crew was equipped with a service truck, necessary tools and equipment, and extensive safety equipment. Their initial task was to catalog and describe all regulators and make physical improvements necessary to permit them to be safely inspected and maintained on a regular basis. Figure 8 shows some of the men with their truck. The ordinances also provided for the establishment, construction, maintenance, and the operation of a regulator control system by the Sanitary District and the payment of costs for the system.

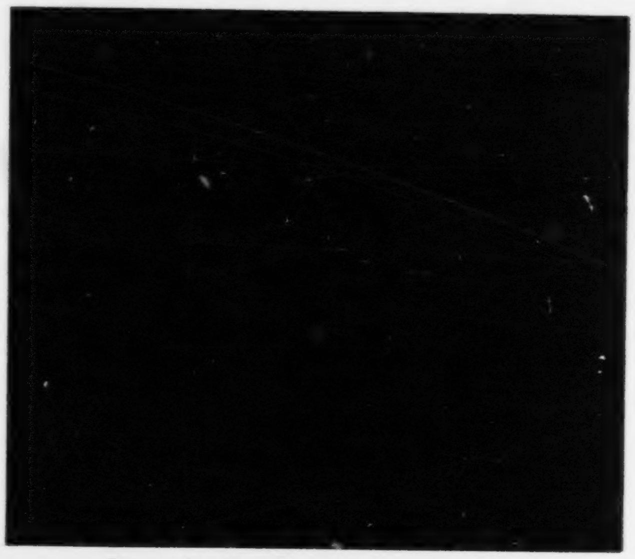

Figure 8. Regulator Crew and Vehicle

Proposed Regulator Control System

The analyses of the interceptors and regulators and rainfall data resulted in the proposal of a regulator control system contained in Volume III of the "Report on the Expansion of Sewage Works in the Minneapolis-Saint Paul Metropolitan Area". (2) The proposed system was described thusly:

> *"It is proposed that a comprehensive control system be initiated to provide an integrated system of regulator operations which will take advantage of the uncontrollable factors affecting the system . . .*
>
> *Any part of the collection system which can be made variable will provide for more efficient use of facilities in the future . . .*
>
> *It is proposed that a system of supervisory control be installed at key regulators and other points in the system to provide regulator operation based on interceptor utilization.*

The operation of regulators at present cannot be based on interceptor level and cannot be varied to meet actual conditions . . .

The system of present regulators has a fixed hydraulic capacity with the variations of quantity admitted to the interceptor sewer varying with the head at each particular regulator and sometimes with the functioning of a gate contolled by level in the trunk sewer.

The float regulator shown in old literature can now be replaced with modern power operated gates controlled by a supervisory system from one control point. Gate positions, flows, and levels in major sewers can be telemetered simply and accurately to rapidly provide a dispatching operator with a picture of instantaneous functioning of the interceptor system.

It is suggested that such a system would prove immediately useful in reducing loss of sanitary sewage at regulators and provide for day by day adjustments to meet changing conditions.

Along with the supervisory control system, it is proposed that modifications be made to non-automated regulators to provide better operation and simplify maintenance. It is proposed that a system of telemetering be installed to provide data on interceptor sewer and trunk sewer levels for operation of the supervisory control, determination of frequency and quantity of overflow of sanitary sewage in actual operation and to provide data for design of future modifications . . .

The proposed system will allow full utilization of existing interceptor sewers. It will also insure a reduction of the quantity and frequency of sanitary sewage overflow to the river . . .

The central control of regulators will allow the choice by an operator of points of bypassing raw sewage in the system based on river conditions at the time . . .

The proposed system could also provide automatic readout of data for analysis, either manually or with computer techniques, to further improve operation of the system . . . In addition, should the separation programs set forth by the central cities not fully materialize, the control system would provide the best means of minimizing loss of sanitary sewage without major expenditures for further modification of regulators".

The Water Quality Act of 1965 included legislation which provided Federal Water Pollution Control Administration matching grants for demonstration projects using new or improved methods for controlling the discharge from combined sewer systems. The Sanitary District, being prepared as a result of the earlier studies, made an application for a Facilities Demonstration Grant in April of 1966. The Sanitary District obtained the first such grant for its proposed project for installation and evaluation of "A Dispatching System for Control of Combined Sewer Losses." The grant amount of $870,750 is 50 percent of the $1,741,500 total project cost.

MSSD Personnel

Because of the size and nature of the project, which involved some new approaches, a separate department or area was essentially created by the Sanitary District. The Project Engineer for the Regulator Demonstration Program had been responsible for the previously initiated Regulator Crew and their duties. This responsibility was retained, and, for the most part, all other time was devoted to the Demonstration Program. During the period from July, 1967 to June, 1969, the Project Engineer had the assistance of another full time Assistant Engineer. Since June, 1969, only one Engineer has worked on the Project. Since September, 1967, the Project group has included a Data Analyst-Logger Operator who was familiar with the sewer system, having worked for three months with the Regulator Crew, and who had data processing training. A secretary was assigned to the Demonstration Program during most of the Period.

The Regulator Crew was utilized for certain work and did all of the sewer sampling. The crew contained four men until the summer of 1968 when week-end sampling was carried on. Its size was increased to five at that time and has remained so because of the added work load.

Two chemists from the MSSD Laboratory were utilized extensively for operation of the Technicon Autoanalyzer. They received training on the equipment, did all of the testing preceding the full scale use of the equipment and operated it during the initial sampling periods. They later trained part time and temporary student employees who were used for operating the equipment seven days per week during 1968.

Five temporary student employees were utilized for Autoanalyzer operations and other purposes during 1968. During the summer of 1966 one student employee was used; during the summer of 1969 three student employees were hired. All temporary help were students at the University of Minnesota, most engineering, chemistry, and mathematics majors. Student employees have performed most of the routine River Monitor maintenance since the monitors were installed.

One of the electricians from the Maintenance Department of the Sanitary District was assigned to the Project in May, 1968, to be used as needed. He has been used between one-half and three-quarter time for telemetry maintenance, river monitor maintenance, calibration and other electrical maintenance work. A pipefitter was employed on the Project full time for about three months.

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III. STUDIES OF SEWAGE STRENGTH DURING DRY AND WET WEATHER

In the sewer systems of Minneapolis and St. Paul variations in composition and quantity of flow are greater than the more well defined variations which occur at the Treatment Plant. Because of this continuous variability, single grab samples or composite samples can not describe the conditions existing adequately enough to assist in real-time operation. Therefore a combined sewer sampling and analytical program was initiated.

The intent of the sewer sampling program was to accumulate a large enough volume of data to enable statistical methods to be used in describing diurnal variations in dry weather sewage composition and the effects of short term transient events, namely rainfall and runoff events. Knowledge of relative pollutional character of waste waters by location and time of day is useful in determining operating procedures from a pollution control standpoint. When rainfall conditions will not permit operation for maximum diversion because of limited interceptor capacity, local differences in pollutional strength of waste water can determine priorities for diversion and bypassing. Data from the runoff events provide information useful in determining the character of combined sewage overflow and evaluation of the magnitude of pollution from this source.

Sampling Program

SERCO automatic samplers were used to obtain hourly grab samples. The samplers hold 24 bottles in a rack; each bottle is connected to an individual sample tube running to the weighted sample head. A portable vacuum pump is used to evacuate the bottles. A clock releases a clamp on one rubber sample tube each hour to collect a grab sample. Usually five samplers were used and five different locations sampled at one time. Each morning, the MSSD's Regulator Crew would visit each sampler, remove the twenty-four marked sample bottles, drain the sample tubes, install a new set of bottles, recharge the vacuum and reinstall the sampler in the sewer.

Sampling was initiated in November, 1966, and some sampling was done through October, 1967, with a total of 633 station days sampled at 14 different stations in the sewer and interceptor system. Sampling began again in March, 1968, and lasted until September 15, 1968, with a total of 832 station days sampled. Figure 9 shows members of the Regulator Crew withdrawing one of the samplers from a manhole to remove the samples and recharge the sampler.

A total of 24 stations were sampled—16 combined sewer regulators, the 3 Minneapolis Interceptors where storm flow relief can occur, 2 other St. Paul Interceptors, and 3 Treatment Plant locations, the raw flow, the primary effluent, and the secondary effluent. Table 6 summarizes the sampling program, showing the number of days of sampling at each location.

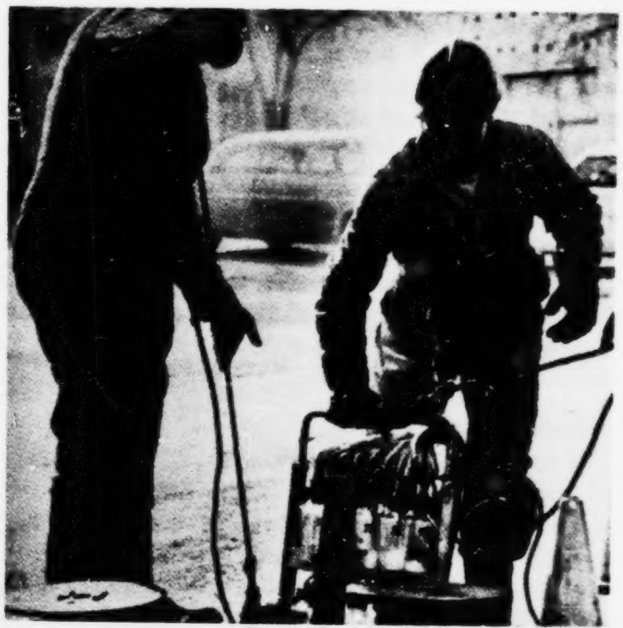

Photo By Kent Koberstein
Courtesy Minneapolis Sunday Tribune

Figure 9. Regulator Crew Servicing Automatic Sampler

Table 6–SUMMARY OF SEWER SAMPLING PROGRAM

Regulator Demonstration Program Sampling Data
November 1966 to September 1968

Station	Station Days Sampled
Plant Secondary Effluent	12
Plant Primary Effluent	27
Plant Raw	307
Belt Line	47
Phalen Creek	63
Trout Brook	58
St. Peter & Kellogg	62
West Seventh Interceptor	43
Rice & Rondo	55
Mississippi River Blvd. Interceptor	35
Otis & Marshall	33
Wabash & Cromwell	11
Wabash & Eustis	65
Minneapolis East Meter	77
Oak Street	73
Second & Main	67
31st & Randolph	61
Minneapolis N.W. Meter	80
26th & Seabury	42
Portland & Washington	18
Camden	61
Minneapolis S.W. Meter	80
38th & Edmund	47
39th & Minnehaha	41
TOTAL	1465

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The Regulator Crew usually devoted the first two hours of each day to servicing samplers. They were met at the last station serviced and the samples were transported to the MSSD Laboratory. Sample days usually ran from 8 A.M. to 8 A.M. Somewhat fewer than the maximum possible 35,160 samples were collected, because of occasional equipment problems leading to loss of a sample. Sampling was resumed during August and September, 1969, when the gaging and monitoring system was operating, but little rainfall occurred during this period.

The samplers have been used frequently within the plant and by the University of Minnesota on pilot plant sampling also.

Automated Analysis

To run analyses on an additional 120 samples daily was beyond the capabilities of the Sanitary District Laboratory, so automatic analysis equipment was acquired. The equipment used was the Technicon Autoanalyzer, a portion of which is pictured in Figure 10. Two MSSD chemists attended a special training course in its use and were able to work out difficulties encountered in adapting the equipment for use in analysis of sewage. The operation of the equipment and its testing prior to sampling have been reported.(3)

Five or six analyses were made on each sample collected, at a rate of 30 samples per hour. The analyses primarily used were chemical oxygen demand, chloride, phosphate, ammonia nitrogen, and total Kjeldahl nitrogen, although the equipment has also been used to measure iron, urea, nitrite nitrogen, nitrate nitrogen, and ABS. The equipment has also been used for analysis of treatment plant samples and, after modification, for analysis of river water samples.

A "common standard" containing all of the components measured was developed. Standards at 5 concentration levels were inserted after every 24 samples. Daily plant composites for raw flow, primary effluent, and secondary effluent were also run in triplicate. The number of discrete samples analyzed ran up to 159 each day.

Data Handling

At an average of 5 analyses per sample, up to 795 discrete analyses were made daily. The analysis results were recorded on continuous strip chart recorders, with peaks on a continuously traced line representing an optical density for each sample and standard run. Calibration curves prepared from the optical densities observed for various standard solution concentrations could have been used to manually convert sample optical density to mg/l. However, this would have

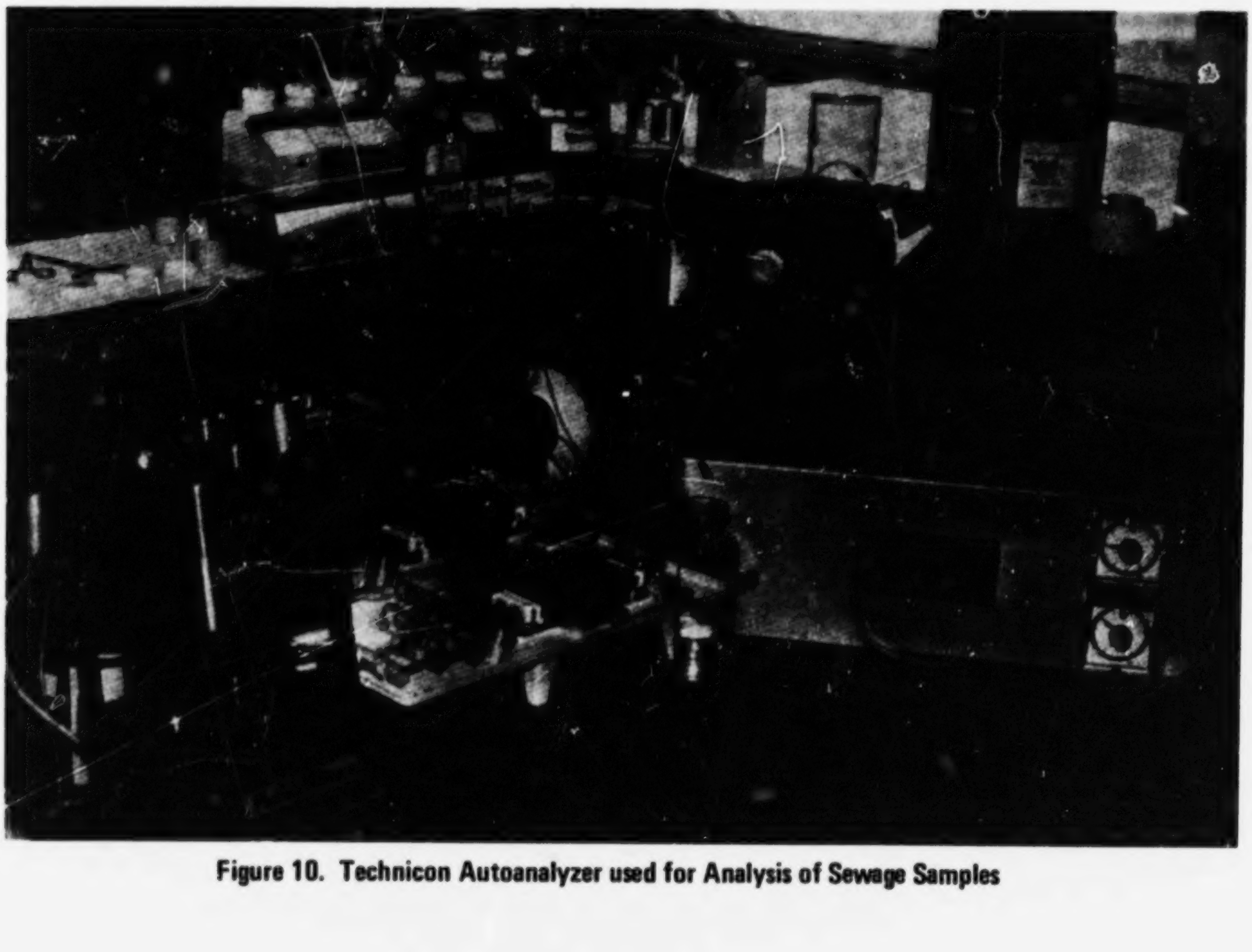


Figure 10. Technicon Autoanalyzer used for Analysis of Sewage Samples

been time consuming because of the number of analyses and because standards were repeated between sets of 24 samples to account for base line variations.

As an alternative to the manual method a machine processing method was developed. A key sheet was designed to be used for keypunching of raw data onto cards, Figure 11. Sample identification and standard concentrations and optical density values for standards and samples were read from the recorder graphs and entered onto the key sheet. A program was written to fit a curve to the standard concentrations and optical densities and to update the curve as standards were repeated to account for base line drift. The program calculates the concentration values and generates a report of scaled values, Figure 12. A program was also written to punch the data onto cards in a format acceptable to the STORET System. The programming was done for MSSD by a programming and systems consultant and data processing computer time was rented from a data processing center.

Now after almost two years of sampling there have been approximately 200,000 discrete analyses, with about 150,000 on sewage samples. Over 6,000 samples and 30,000 analyses were for the plant raw waste. On the average about 1,200 samples and 6,000 analyses were obtained from each of 21 other locations in the sewer system.

Storage within the STORET System was easily accomplished. An example of a retrieval report, generated in Washington by the STORET System is shown in Figure 13. Hourly sewage strength data for a few days at one of the control and monitoring regulators in St. Paul are listed. The STORET analysis program was used to obtain the number of observations, maximum, minimum, mean, and standard deviation for each analysis at each station by month, by quarter, by year, and by period of record.

Variations in concentration occurring on any particular day are often large as Figure 14, a machine plot from the STORET system, shows. COD concentration in mg/l is plotted for a regulator in St. Paul over a 70 day period beginning on March 18, 1968. Wet and dry weather analysis results are included in the data. There are up to 24 data points plotted vertically for each day, and COD concentration on any day varies considerably. Recurring periods of higher plotting density indicate the lower variability of COD on Saturday and Sunday at this regulator.

Using data center facilities and the services of our programming consultant the data were further processed. Distributions by hour were made for all data at each station. Frequency distributions have been plotted for some hours for each analysis at each station. The diurnal variations in COD shown on Figure 14 were not found to be regular, for most hours of the day were distributed quite widely. Some frequency distributions skewed on rectangular coordinate paper plotted normally on semi-log paper. Figure 15 is an example of one of these plots, showing frequency distributions of COD data from the Minneapolis S.W. Interceptor for four hours.

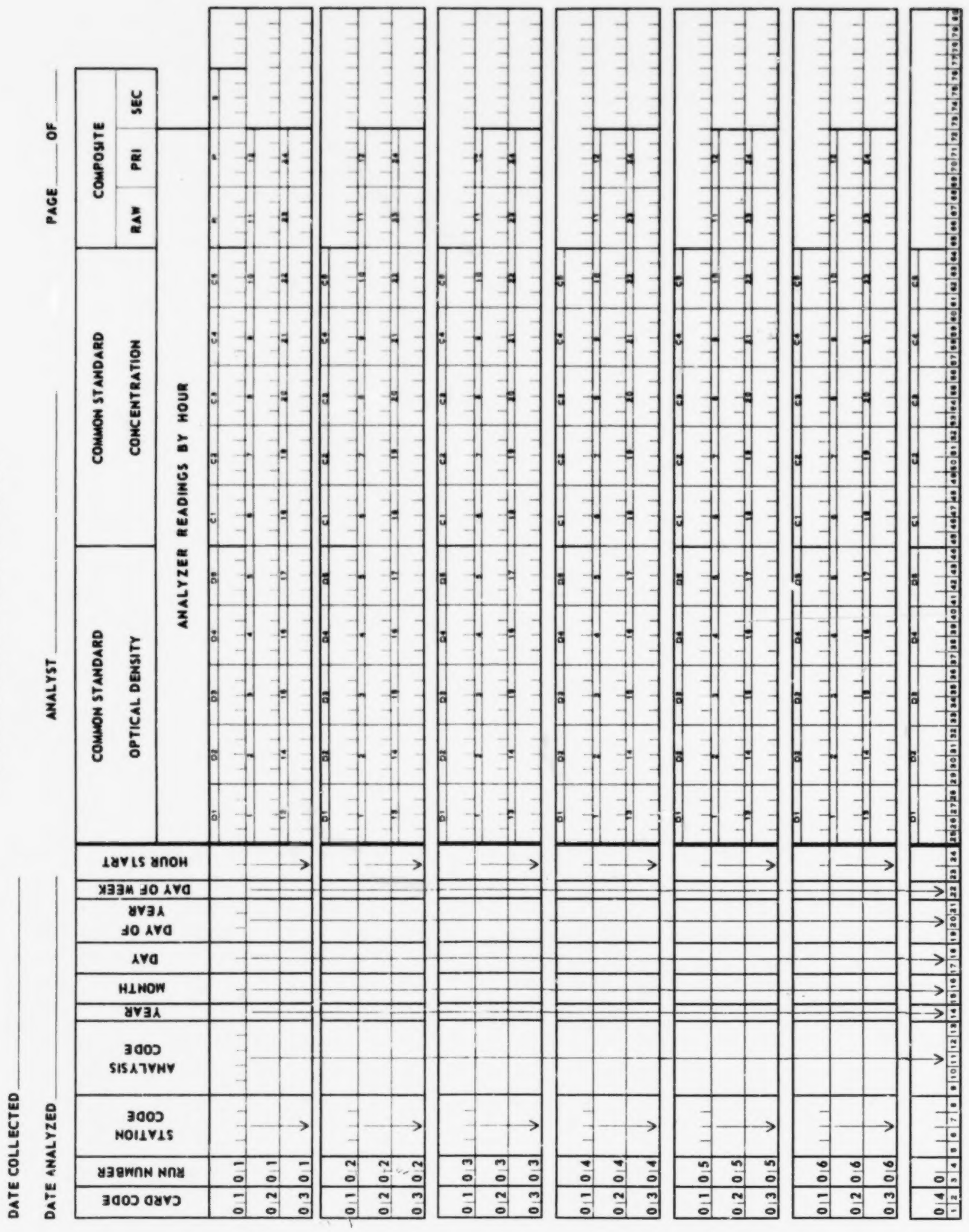
Plots of maximum, minimum, and mean have been prepared on 24-hour graphs to illustrate diurnal variations. These functions for COD data from the Minneapolis S.W. Interceptor are shown in Figure 16. The distribution of values within the extremes could be quite varied, so it is informative to be able to illustrate both at once. The 24-hour and frequency distribution plots were combined in a few instances to create three-dimensional plots such as Figure 17, which shows the range and frequency distribution of hourly treatment plant raw wastewater COD data. Included in the plot are both wet and dry weather values.

Continuously recorded flow information was also available so loadings could be calculated. The plant raw waste flow and sewage flow from each of the three Minneapolis Interceptors is metered and recorded at the treatment plant on 24-hour circular charts. Hourly readings from these charts were transferred to specially prepared key sheets, Figure 18. Flow data from November, 1966, through June, 1969, has been punched onto cards. Over 180,000 hourly flow values have been transferred and recorded in this manner.

Distributions of plant and interceptor flows by hour have been made and plotted. Statistical analysis runs producing number of observations, maximum, minimum, and mean have also been made and 24-hour plots have been drawn, and some three-dimensional plots have been prepared. Diurnal flow variations at four places in the system have thus been well described. This will also assist in formulating operational strategies. Flow variations with season have been shown by distributions by month.

Loadings in pounds per hour were calculated from the hourly Technicon analysis results and the hourly flow values and distributed by hour of day, by day of week, and by month for the plant raw waste. Plant hourly flow values used in calculating loadings are those taken through the treatment plant. Primarily because of a deficiency in grit channels, portions of high flows caused by storm runoff which exceed safe limits are bypassed. Bypass flow volumes are estimated, but are not included in the loading calculations.

Comparison of the by month frequency distributions of hourly plant loadings indicates that there is no predictable effect of storm flow on plant loading. In 1967 the months of May and August had 0.61 in. and 2.79 in. of rainfall respectively. In 1968 the same two months had 3.74 in. and 0.75 in. of rainfall. The distribution of hourly COD loadings for May, 1968, with over six times the rainfall of May, 1967, plotted to the left of May, 1967, indicating lower loadings. The distribution for August, 1967, with almost four times



MINNEAPOLIS-SAINT PAUL SANITARY DISTRICT
AUTOMATIC ANALYZER LOADING AND RESULT

DATE COLLECTED ______
DATE ANALYZED ______
ANALYST ______
PAGE ____ OF ____

CARD CODE	RUN NUMBER	STATION CODE	ANALYSIS CODE	YEAR	MONTH	DAY	DAY OF YEAR	DAY OF WEEK	HOUR START	COMMON STANDARD OPTICAL DENSITY	COMMON STANDARD CONCENTRATION	COMPOSITE RAW	COMPOSITE PRI	COMPOSITE SEC
0 1	0 1									D1 D2 D3 D4 D5	C1 C2 C3 C4 C5	R	P	S
0 2	0 1									1 2 3 4 5	6 7 8 9 10	11	12	
0 3	0 1									13 14 15 16 17	18 19 20 21 22	23	24	
0 1	0 2													
0 2	0 2													
0 3	0 2													
0 1	0 3													
0 2	0 3													
0 3	0 3													
0 1	0 4													
0 2	0 4													
0 3	0 4													
0 1	0 5													
0 2	0 5													
0 3	0 5													
0 1	0 6													
0 2	0 6													
0 3	0 6													
0 4	0									D1 D2 D3 D4 D5	C1 C2 C3 C4 C5			

ANALYZER READINGS BY HOUR

Figure 11. Autoanalyzer Data Key Sheet

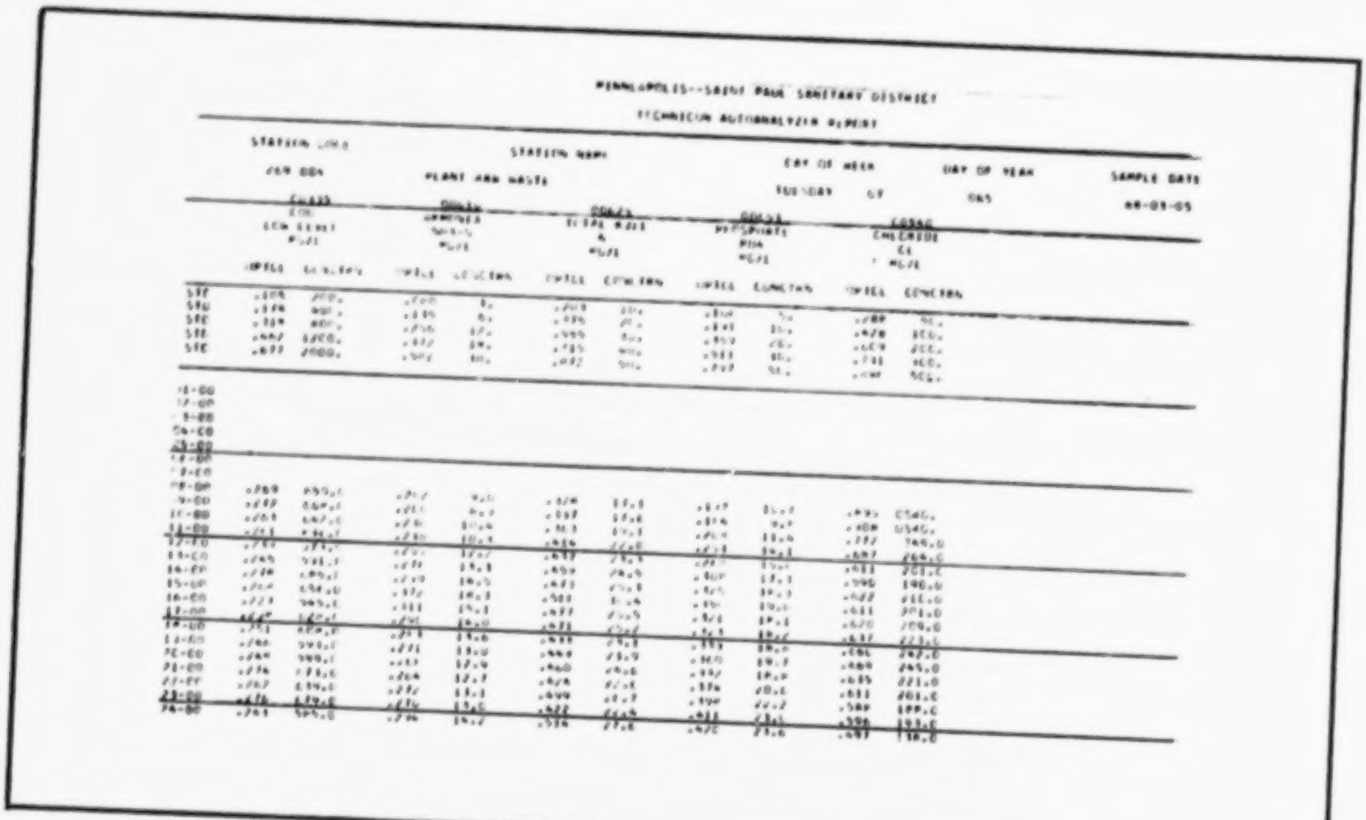
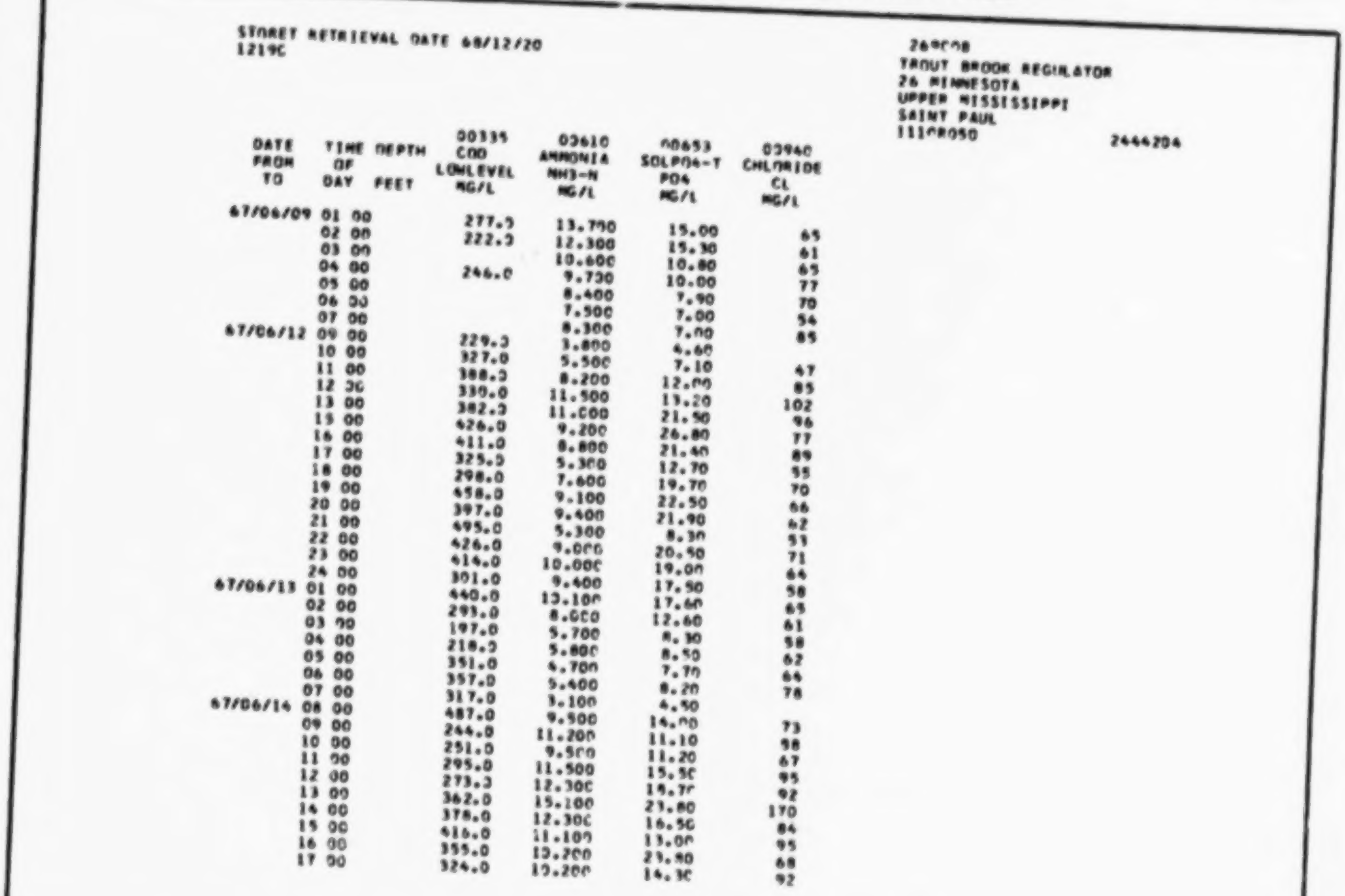


Figure 12. Technicon Autoanalyzer Report of Scaled Values



```
STORET RETRIEVAL DATE 68/12/20                                  26RC08
1219C                                                           TROUT BROOK REGILATOR
                                                                26 MINNESOTA
                                                                UPPER MISSISSIPPI
                                                                SAINT PAUL
                                                                111CR050              2444204
                           00335      00610      00653      00940
DATE      TIME  DEPTH      COD       AMMONIA   SOLPO4-T   CHLORIDE
FROM       OF            LOWLEVEL     NH3-N       PO4        CL
TO         DAY  FEET       MG/L       MG/L       MG/L       MG/L
67/06/09  01 00            277.0     13.700      15.00        65
          02 00            222.0     12.300      15.30        61
          03 00                      10.600      10.80        65
          04 00            246.0      9.730      10.00        77
          05 00                       8.400       7.90        70
          06 00                       7.500       7.00        54
          07 00                       8.300       7.00        85
67/06/12  09 00            229.0      3.800       4.60
          10 00            327.0      5.500       7.10        47
          11 00            388.0      8.200      12.00        85
          12 00            339.0     11.500      13.20       102
          13 00            382.0     11.000      21.50        96
          15 00            426.0      9.200      26.80        77
          16 00            411.0      8.800      21.40        89
          17 00            325.0      5.300      12.70        55
          18 00            298.0      7.600      19.70        70
          19 00            458.0      9.100      22.50        66
          20 00            397.0      9.400      21.90        62
          21 00            495.0      5.300       8.30        53
          22 00            426.0      9.000      20.50        71
          23 00            414.0     10.000      19.00        64
          24 00            301.0      9.400      17.50        58
67/06/13  01 00            440.0     13.100      17.60        65
          02 00            293.0      8.000      12.60        61
          03 00            197.0      5.700       8.30        58
          04 00            218.0      5.800       8.50        62
          05 00            351.0      4.700       7.70        64
          06 00            357.0      5.400       8.20        78
          07 00            317.0      3.100       4.50
67/06/14  08 00            487.0      9.500      14.00        73
          09 00            244.0     11.200      11.10        98
          10 00            251.0      9.500      11.20        67
          11 00            295.0     11.500      15.50        95
          12 00            273.0     12.300      19.70        92
          13 00            362.0     15.100      23.80       170
          14 00            378.0     12.300      16.50        84
          15 00            416.0     11.100      13.00        95
          16 00            355.0     13.200      23.90        68
          17 00            324.0     13.200      14.30        92
```

Figure 13. STORET Retrieval of Hourly Sewage Analyses

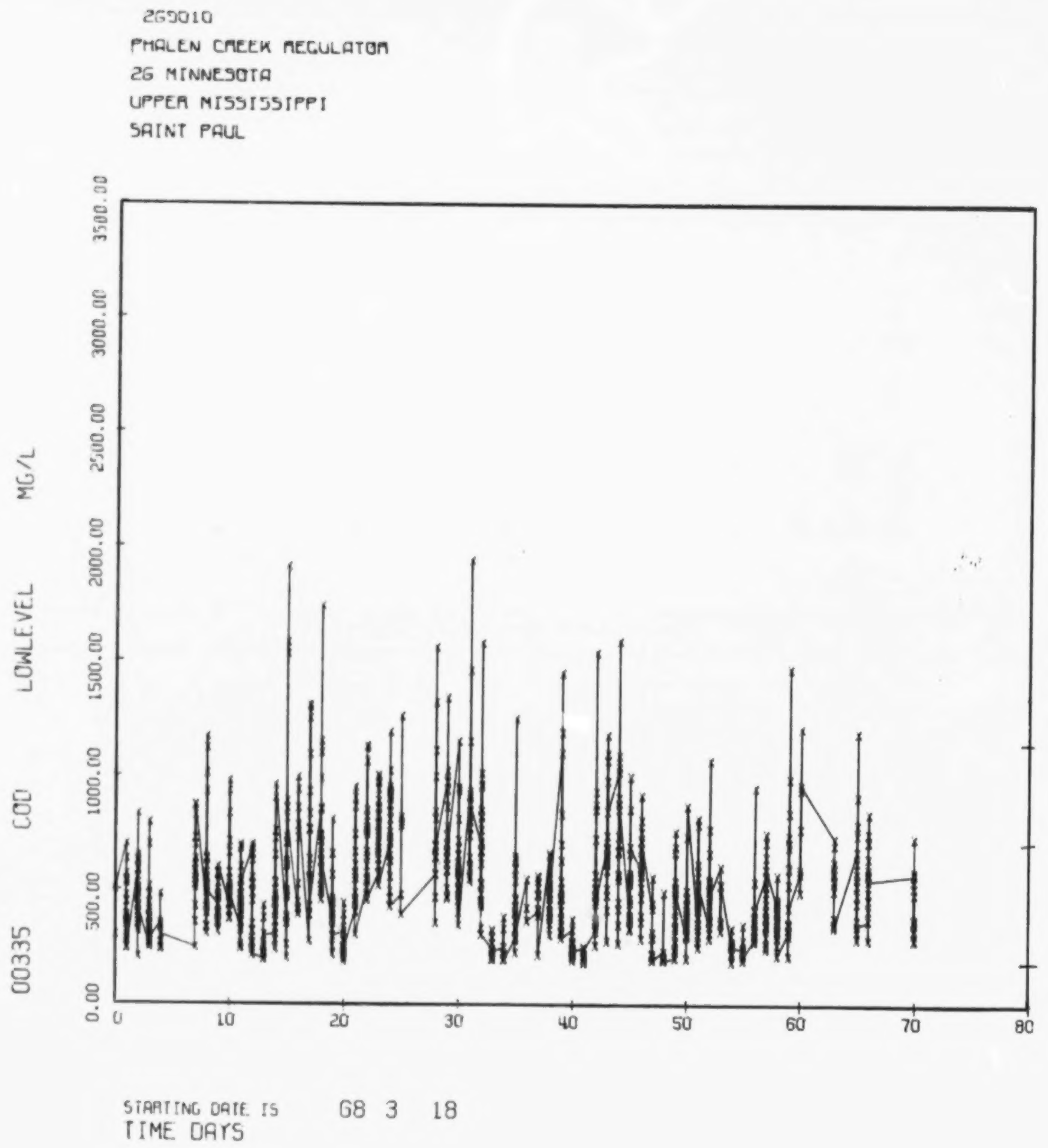


Figure 14. Machine Plot of Hourly COD Data

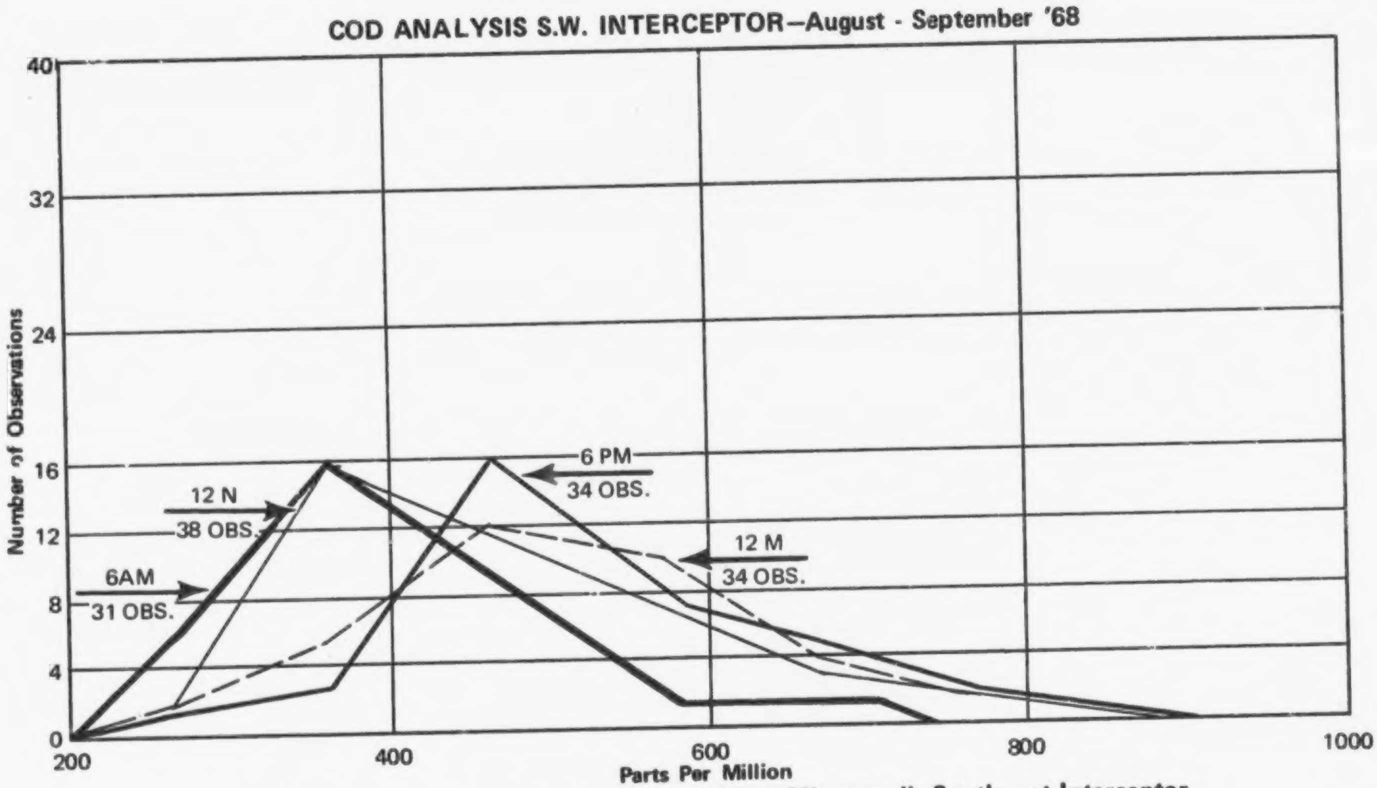


Figure 15. Frequency Distributions—COD at Minneapolis Southwest Interceptor

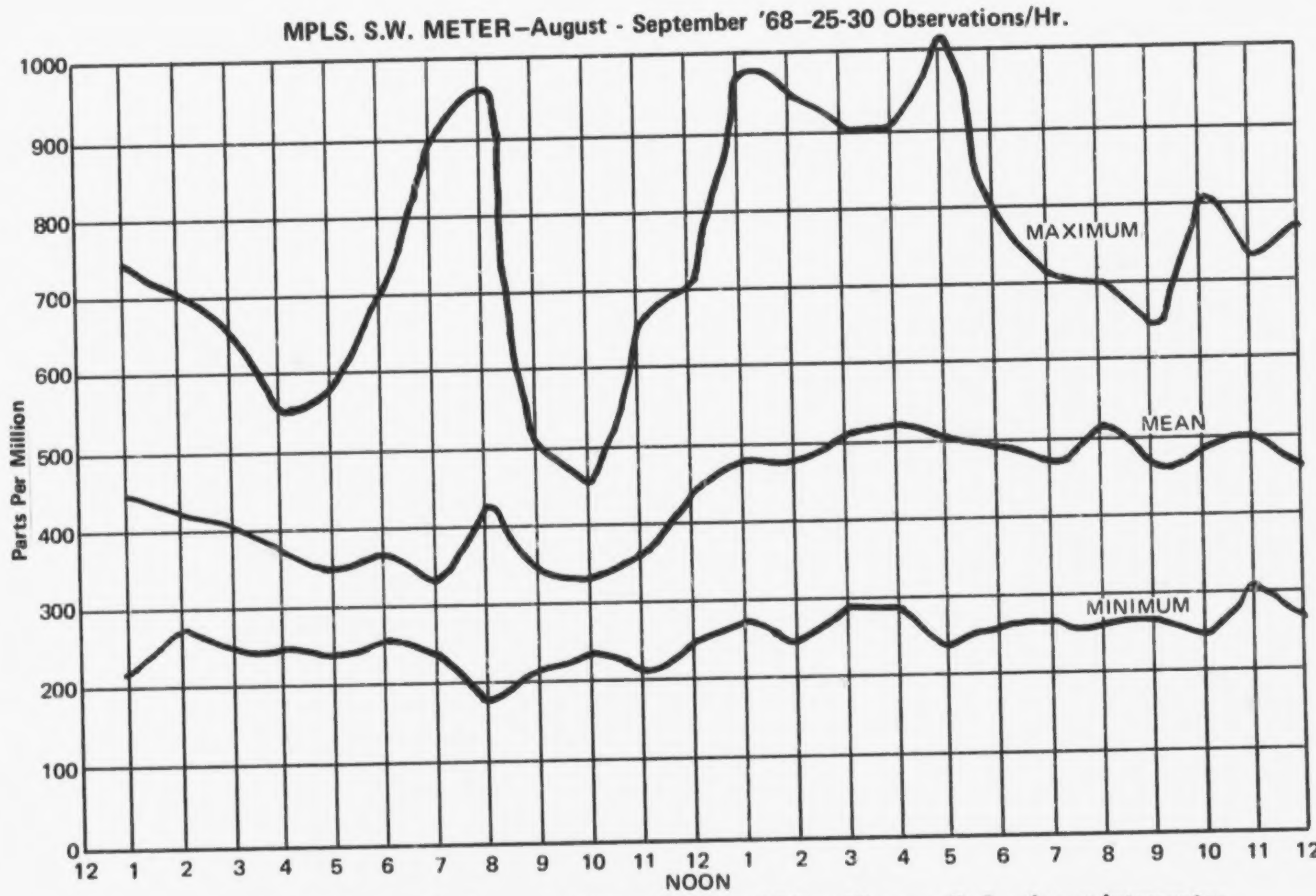
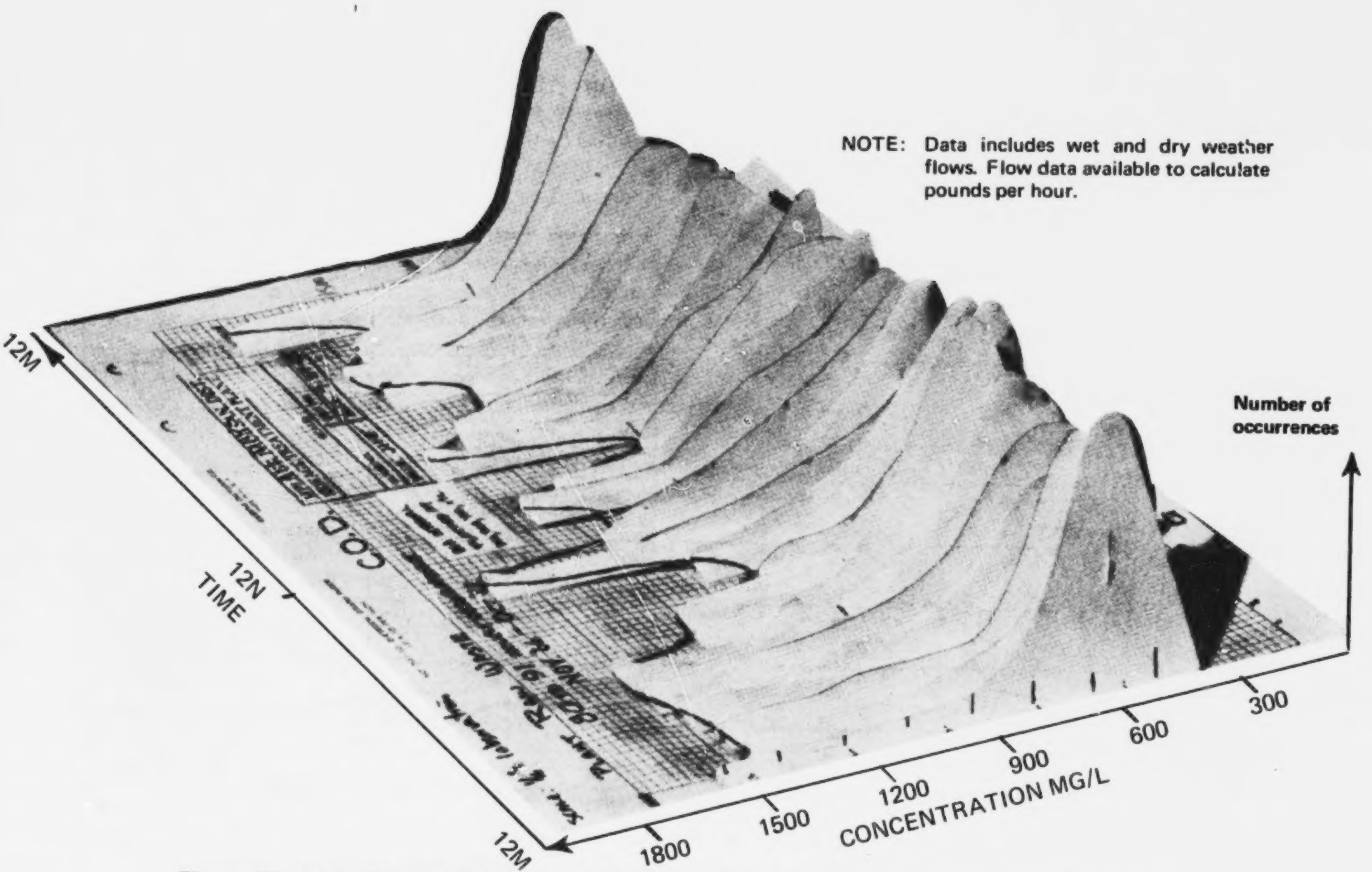
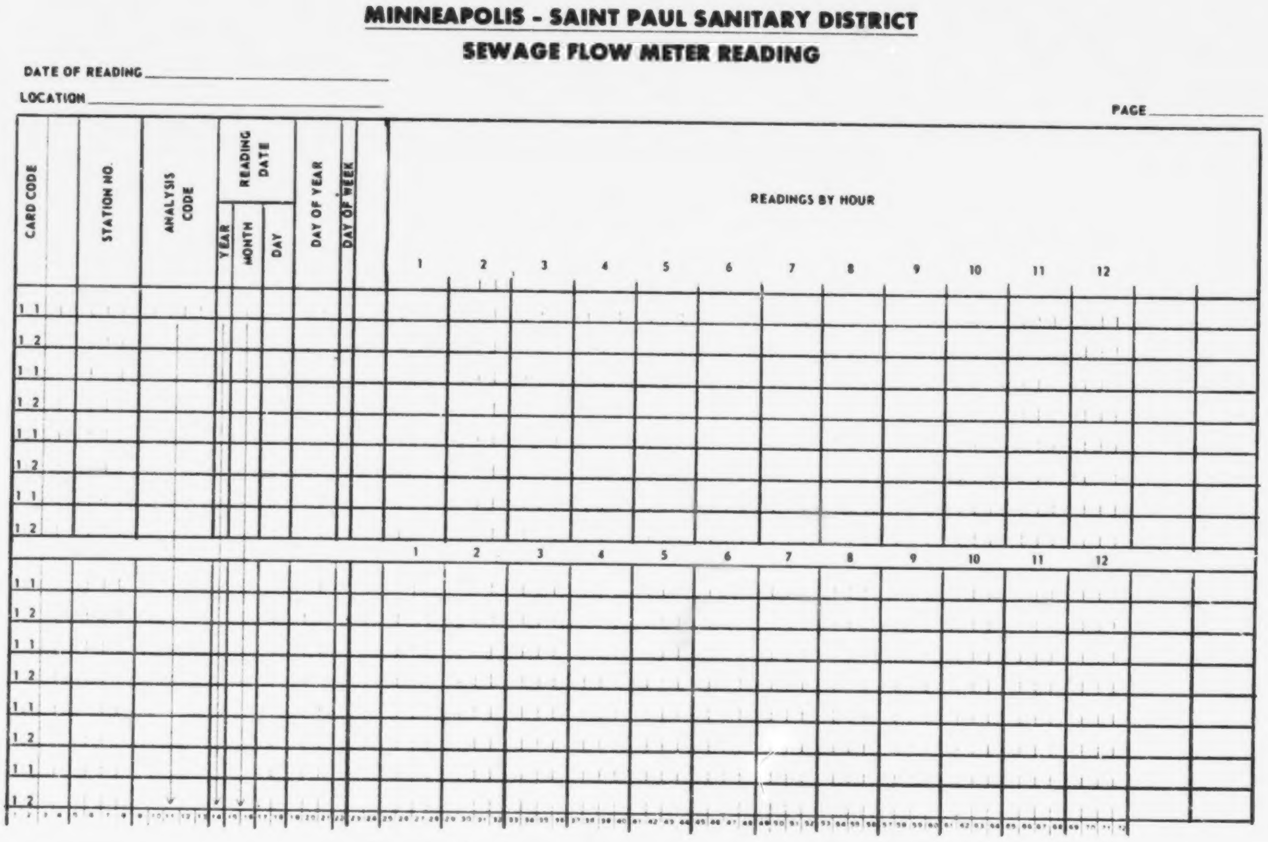


Figure 16. Minimum, Maximum, and Mean-24 Hour COD at Minneapolis Southwest Interceptor



NOTE: Data includes wet and dry weather flows. Flow data available to calculate pounds per hour.

Figure 17. Three-Dimensional Plot of 24-Hour COD Data for Treatment Plant Raw Wastewater



MINNEAPOLIS - SAINT PAUL SANITARY DISTRICT

SEWAGE FLOW METER READING

DATE OF READING________________

LOCATION________________

PAGE________

CARD CODE	STATION NO.	ANALYSIS CODE	READING DATE			DAY OF YEAR	DAY OF WEEK	READINGS BY HOUR											
			YEAR	MONTH	DAY			1	2	3	4	5	6	7	8	9	10	11	12
1 1																			
1 2																			
1 1																			
1 2																			
1 1																			
1 2																			
1 1																			
1 2																			
								1	2	3	4	5	6	7	8	9	10	11	12
1 1																			
1 2																			
1 1																			
1 2																			
1 1																			
1 2																			
1 1																			
1 2																			

Figure 18. Sewage Flow Meter Reading Key Sheet

the rainfall of August, 1968, plotted to the right, indicating heavier loadings. The months of June in 1967 and 1968 had 7.53 in. and 6.78 in. respectively and the frequency distributions nearly coincide. Figure 19, shows the comparison of COD loadings for May and August of 1967 with 1968.

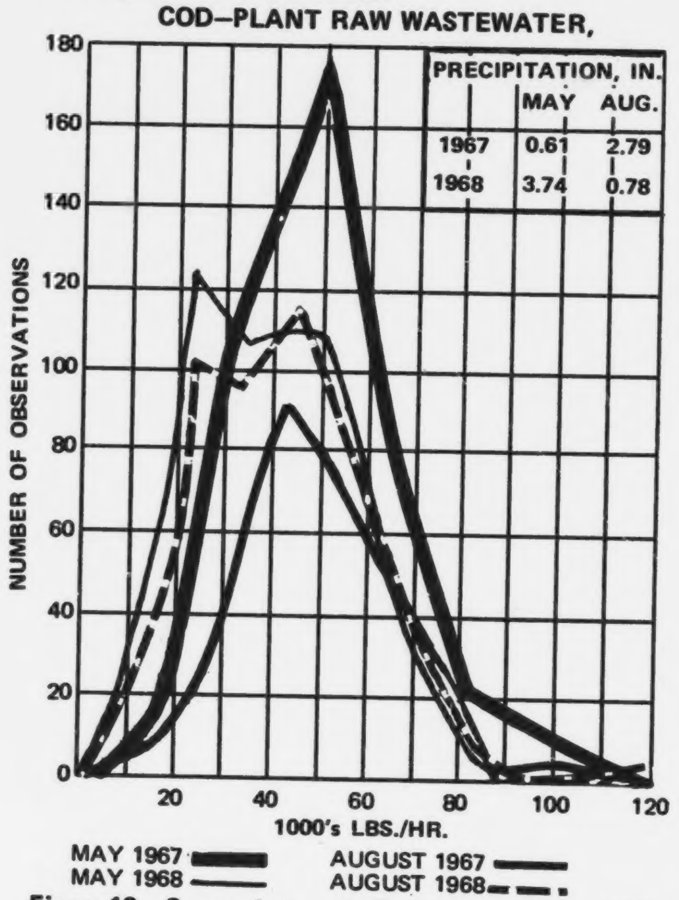


Figure 19. Comparison of Treatment Plant COD Loadings by Month.

The effect of rainfall and runoff on the combined sewer system is readily observable on the flow meter charts for Minneapolis Meters. Figure 20, shows the effect on the Minneapolis N.W. Interceptor of 0.26 in. of rain which occurred on the evening of September 24, 1969. The time during which combined runoff water and sewage is flowing through the meters can easily be identified and punched onto cards. The card format used contains a card code number, the station coding, the year, month, day, and the hour combined sewage flow starts and the day and hour it stops. With this information, a separation of wet weather Technicon loading data at the treatment plant has been made and distributions made on the wet weather data. The same has been done at the Minneapolis Meters and could be done for concentration data at all the other regulators where sampling was carried on.

The frequency distribution of 274 hourly COD loading values representing storm flow periods at the Treatment Plant is compared in Figure 21, with the frequency distribution of 4138 hourly COD loading values representing both dry weather and storm flow periods. In general, most of the COD plant loadings fall within the same usual range during both dry weather and storms. Similar dry weather-storm comparisons were made for calculated hourly plant loadings of Total Kjeldahl Nitrogen, Total Soluble Phosphate, and Chloride ion. The results were similar to those seen for COD. The data representing storm flow almost always lay within the extremes of the dry weather data. The frequency distributions for wet and dry weather Kjeldahl Nitrogen loadings were very similar. Those comparing wet and dry weather phosphate and chloride loadings suggested that during storm periods some dilution of those constituents occurs.

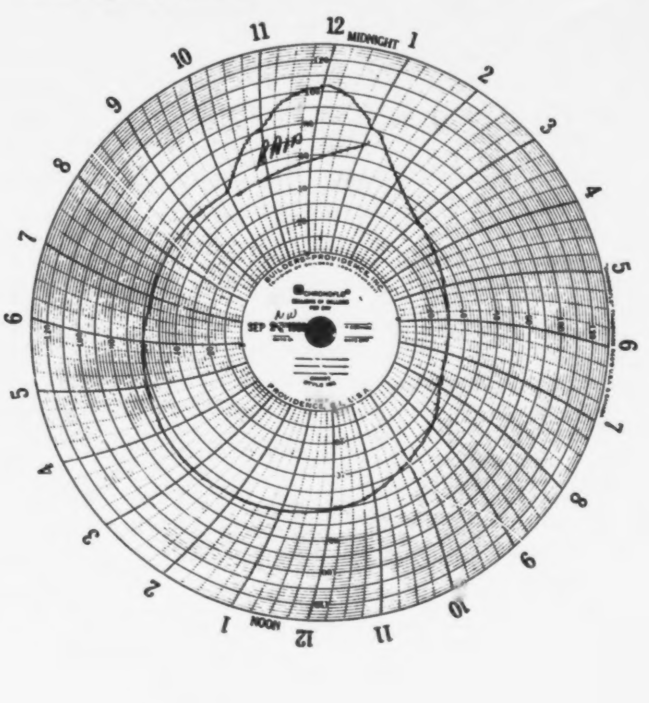
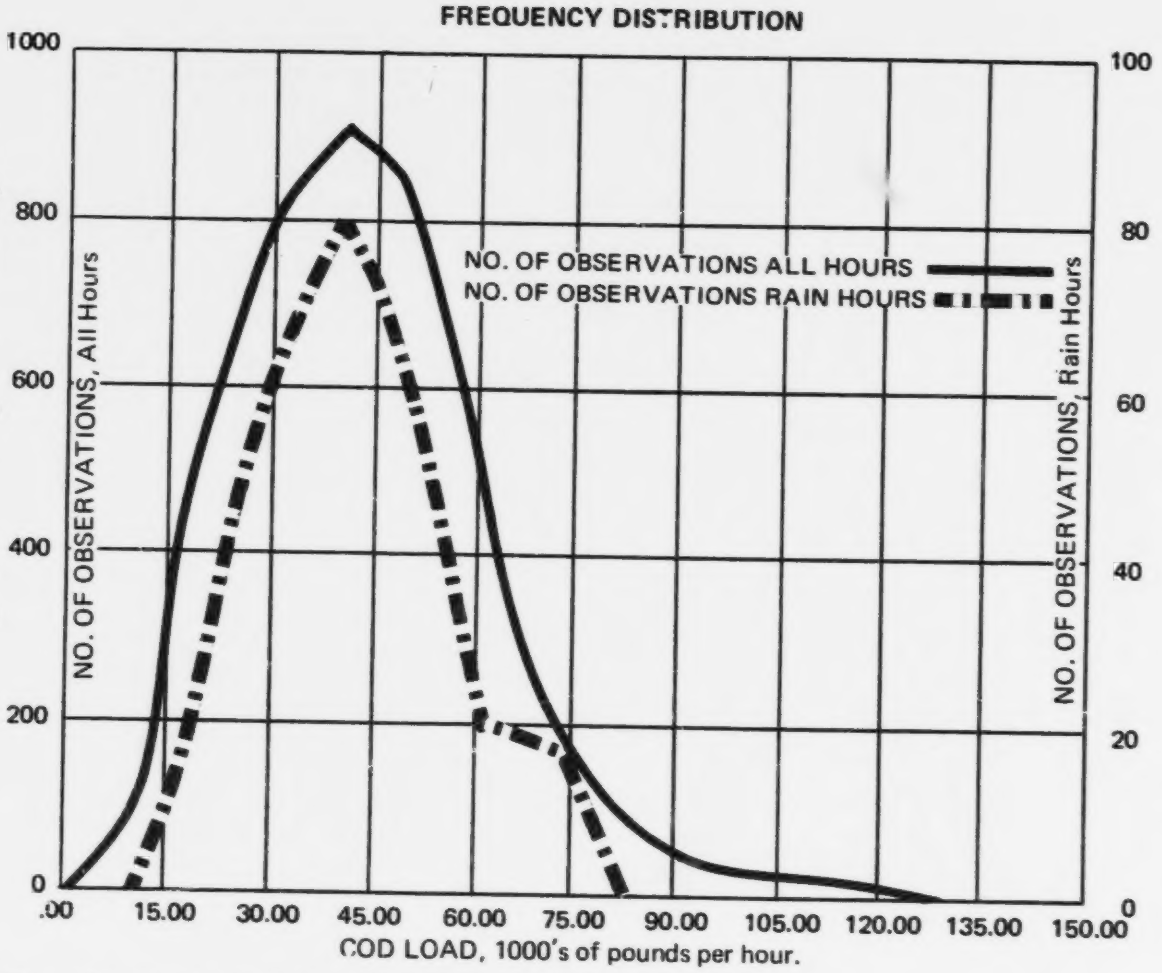


Figure 20. Flow Meter Recorder Chart Showing Effect of Rainfall on the Minneapolis Northwest Interceptor



ALL HOURS:

Observ.	4138
Interval	10.0
Max	176.88*
Min.	1.08
Mean	43.56
S.D.	17.96

RAIN HOURS:

Observ.	274
Interval	10.0
Max	176.88*
Min	14.07
Mean	43.78
S.D.	17.51

*This value is not significant and should have been thrown out.

Figure 21. Plant Raw Wastewater COD Loadings–All Hours and Stormflow Hours

Concentration data for some specific rainfall events were reviewed also. An example of some of this data is presented in Figure 22. A rainfall amount of 0.67 in. occurring over a five hour period was measured at the Weather Bureau gage in South Minneapolis on September 8, 1968, a Sunday. The flow data and COD concentration data at the Minneapolis N.W. and S.W. Meters for this day were compared to those occurring on a dry Sunday two weeks earlier. The concentration values are unaffected by the storm water in the system. Similar studies of other concentration data as well as COD data for other rains at other sampling stations was inconclusive.

Very likely what is measured may be a combination of three possibilities. In some parts of the sewer system storm water is probably diluting wastewater while elsewhere a first flush of sewer deposits may be occurring and still elsewhere the stormwater may be polluted about as much as the wastewater it mixes with. This would especially seem likely at the Treatment Plant where the arriving flow is such a composite of wastewater and stormwater from such a large area.

Because the net effect of stormwater on the strength of the combined flow at the treatment plant is small, one must conclude that combined sewer overflows can affect the river. At least some of the combined sewer overflows must be as polluted or more polluted than the dry weather flow that is usually diverted to the interceptor.

Some of the large mass of data accumulated on hourly wastewater strength and flow have been analyzed. All the data are, however, stored on magnetic tape and punched cards and can be analyzed using data processing techniques. Most of the data is also stored with the FWQA STORET system. Hopefully important use of this data is yet to come.

One immediate use of the data by the MSSD has been in establishing bypass priorities for use in system operation and flow routing when storm flow conditions are such that interceptor capacity is limited.

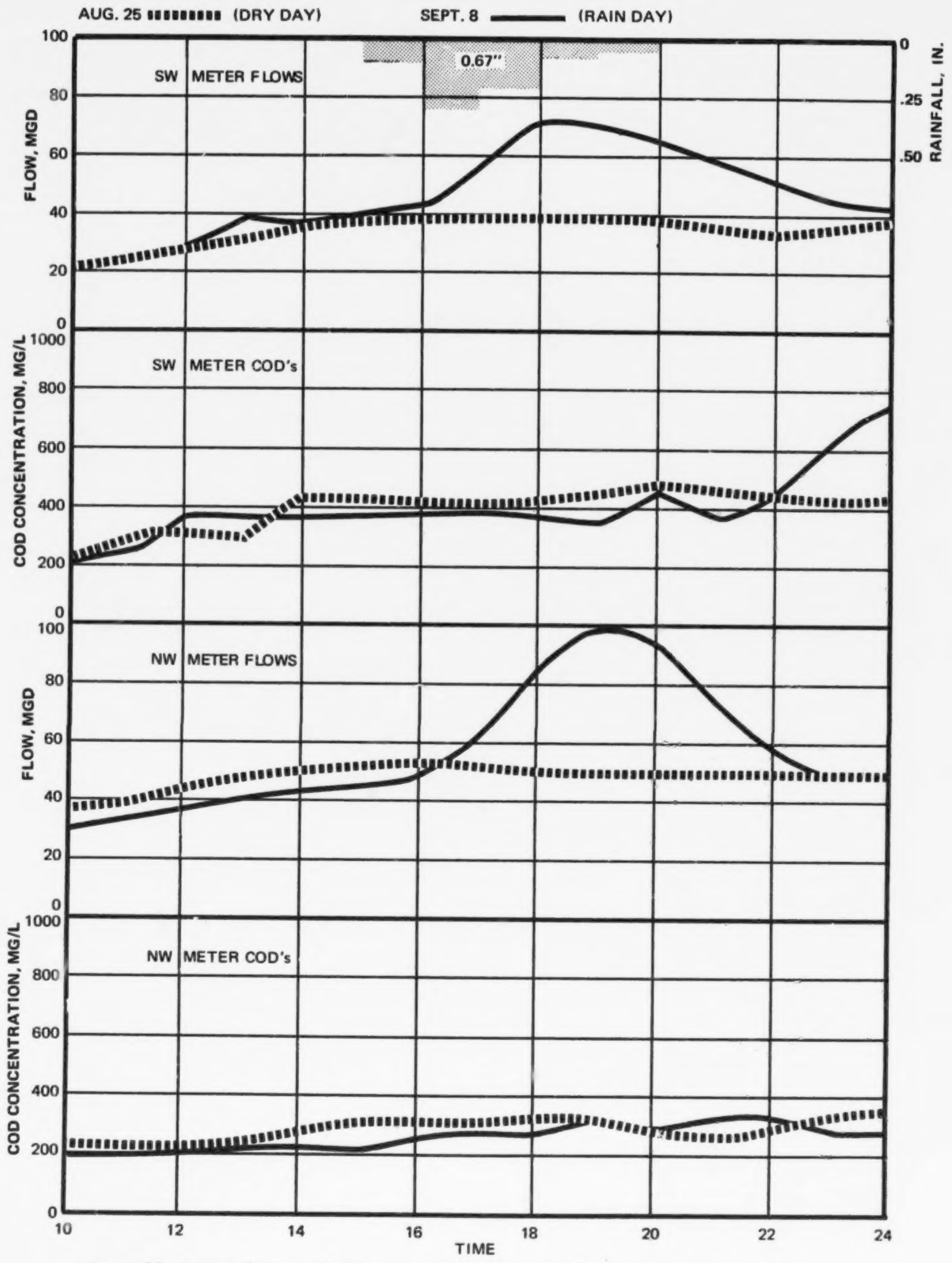


Figure 22. Sewage Flow and COD Concentration Compared for a Dry Day and a Wet Day

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IV. INSTALLATION OF GAGING SYSTEM

In-Sewer Work by Regulator Crew

The Sanitary District's consultants had, as part of earlier studies, successfully used a gaging system employing a pressure-conveying tube installed in the sewer, an air-supply cylinder, a bubbler and a local recorder. A similar approach was planned for use with the Regulator Demonstration Program system with a pressure transducer and telemetry replacing the local chart recorder. The installation of bubbler elements and pressure transmitting tubing in the sewers was accomplished entirely by the Sanitary District's Regulator Crew. Much of the work was done at night to take advantage of low flow depths, making possible the installation of most air discharge elements at or near the sewer invert. Originally, all the elements were made from 1/4" flexible copper tubing with several rows of holes spaced at 90° intervals to provide multiple air discharge ports. Some of these have since been replaced with galvanized pipe elements.

Forty elements were installed at regulators, usually with three per regulator: one upstream from the regulator in the trunk sewer, one downstream from the regulator in the outlet pipe carrying diverted flow to the interceptor and one downstream from the diversion dam in the storm water overflow pipe. Eight elements were installed in the interceptors. Existing level monitoring elements were already in use at three interceptor locations and three regulator locations. All elements were terminated in a safe location in a manhole well above maximum flow depths and 1/4" I.D. plastic tubing used to transmit air pressure to the surface. The Regulator Crew has since maintained the tubing and elements, making repairs and replacements as necessary.

Contract 664A

In order to avoid expensive construction in existing congested urban locations and to provide a "clean" location for electrical and mechanical equipment, pre-cast concrete vaults, identical to those used by the power and telephone industries, were specified as part of Contract 664A. Fourteen vaults were installed near regulators where revisions were to be made for control and monitoring.

Seven pole-mounted cabinets (Figure 23) were installed near interceptor monitoring stations where less space for equipment was required. One vault was used for interceptor monitoring equipment to serve a station located within a city park where an above-ground cabinet was aesthetically undesirable.

The concept of a sealed "umbilical" connection to the hazardous environment of the sewer was developed. The facilities entering the sewer atmosphere were restricted to non-hazardous low pressure air, oil hydraulic and low voltage direct current (five volts at very low current).

Contract 664A also included the electrical service, vault to stub pole telephone wires and bubbler panels for flow depth measurement. The contract was completed during the summer of 1967. Early installation of electric services facilitated later work under other contracts and by Sanitary District personnel. The bubbler cabinets contained a high-pressure air manifold, pressure reducing valve and bubbler, an electric 24-hour clock and a purge timer and a solenoid valve to switch high-pressure purge air into the tubing to purge the element once every 24 hours. Purge time is adjustable and a 10 second purge has been used satisfactorily. Originally compressed air cylinders were used to supply bubbler air, but these were all replaced by small compressor-tank outfits. This has eliminated the problem of changing heavy cylinders periodically in poorly accessible locations.

Rain Gages

The original rain gage network was comprised of eight rain gages; a ninth rain gage was added during the summer of 1969. The rain gages used are Belfort Model 5915 Rainfall Transmitters. The principle of operation is weight measurement, with the scale pan movement transmitted mechanically to a single turn precision potentiometer. The power supply for potentiometer excitation is supplied from the telemetry equipment and the voltage analog proportional to rainfall equivalent weight is transmitted to the central station. One of the gages is shown in Figure 24 with collector and case removed to show the collector pail and weighing mechanism.

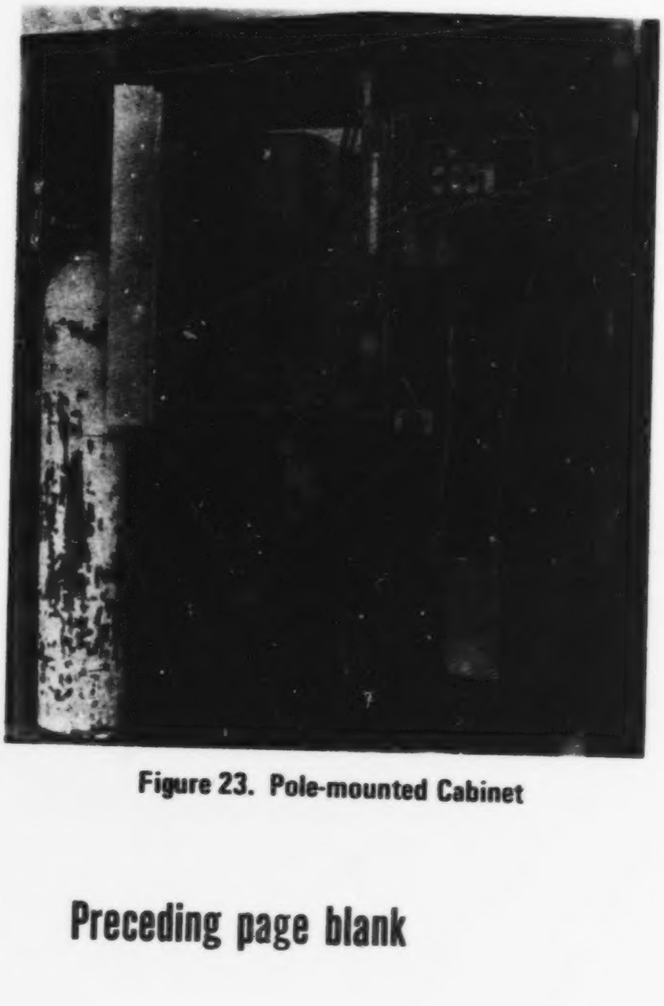

Figure 23. Pole-mounted Cabinet

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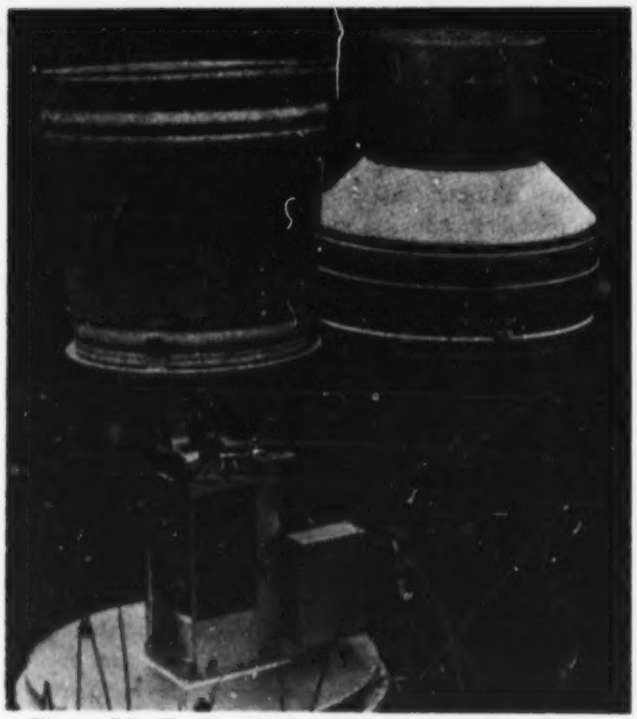

Figure 24. Transmitting Weighing-type Rain Gage

Seven of the eight original rain gages constitute separate remote stations. The eighth original gage is connected to a river monitor station interrogation matrix and did not require a separate station telemetry installation.

Rain gage locations were chosen by the project staff. Initial letters requesting cooperation regarding installation of rain gages and telemetry equipment at various municipal sites were sent during the summer of 1966. Among the requirements for a site were: (1) a suitable rain gage location where representative rainfall measurement could be made, (2) an indoor location within reasonable distance from the gage site where telemetry equipment could be installed and connected to 110 volt AC power and telephone wires, (3) the capability of installing wires between the gage and the telemetry equipment, and (4) a location where vandalism would not be anticipated. In general, locations around the periphery of the Twin Cities were chosen so that storm fronts could be observed as they moved toward combined sewered areas. Surprisingly, it was quite difficult to find sites meeting the general requirements on publicly owned facilities. An attempt was made to site a gage on the plant grounds of large corporation, but approval could never be obtained from the various corporate departments and the attempt was abandoned. The locations finally used were the following: Minneapolis Water Treatment Plant, St. Paul Water Department Reservoir, St. Paul Water Department Pumping Station, University of Minnesota Agricultural Plots, Suburban City Halls (2), and Metropolitan Airports Commission Maintenance Garage.

The ninth gage was installed at a regulator control and monitoring station and connected to the spare telemetry address there. This location is near the center of the Twin Cities. The locations of the nine rain gages are shown on Figure 25.

Installations of the eight initial gages were made by a local electrical contractor. Direct burial cable and conduit were used in connecting the rain gage to the building in which the telemetry equipment was located. At one site direct burial cable was replaced by buried conduit after gophers chewed the insulation off the wires. The ninth gage was installed by the Sanitary District electricians.

The gages seemed susceptible to lightning damage and several of the precision potentiometers were damaged and needed replacement. Several standard replacement potentiometers, which were specially wound for Belforte, were purchased at a cost of about $90 each. Later, a stock item potentiometer that could be used with slight modifications was found to be available for about $20, with no noticeable difference in precision or linearity. Fuses were installed on all rain gage circuits and several fuses subsequently have blown while no damage to the potentiometer occurred, so they may be a worthwhile addition.

A range of 0 to 5 volts was equivalent to 0 to 6 inches of precipitation. Transmission "noise" appeared to be causing variations in scaled readings of as much as ± 0.02 inches. A change of 0.04 inches over a five-minute interval would be equivalent to a rainfall rate of 0.48 inches/hour, so this noise could produce rainfall data unacceptable to the mathematical model. Repeatability tests on the telemetry equipment indicated that its performance was acceptable and that improvements could not likely be made. Noise could be introduced by induction in the cable connecting the rain gage or by the leased telephone lines. Improvements were made by changing the transmission sampling procedure used at the central station to eliminate the effect of any transient noise. Now 16 readings of the A/D output are averaged. If any of the readings differ by more than one per cent from the first reading, a new set of 16 readings are taken.

To further insure accurate rainfall data the collector area of the rain gages was increased by a factor of three by installation of a rain amplifier. Each increment of rainfall therefore became equivalent to three times as large a voltage increment as before and any noise reduced in significance by 1/3. The rain gage data is now accurate to the nearest 0.01 inch. The rainfall collector buckets must be emptied more often, but this has not been intolerable, and a method of remote control emptying will likely be devised for future use.

The use of remote transmitting rain gages has elicited interest from meteorologists in the area. The State Climatologist, along with University of Minnesota scientists, is studying the micro-meteorology of the metropolitan area, and we are supplying him with data from the rain gage system. Data has also been supplied to the public works departments of the suburbs in which gages are installed.

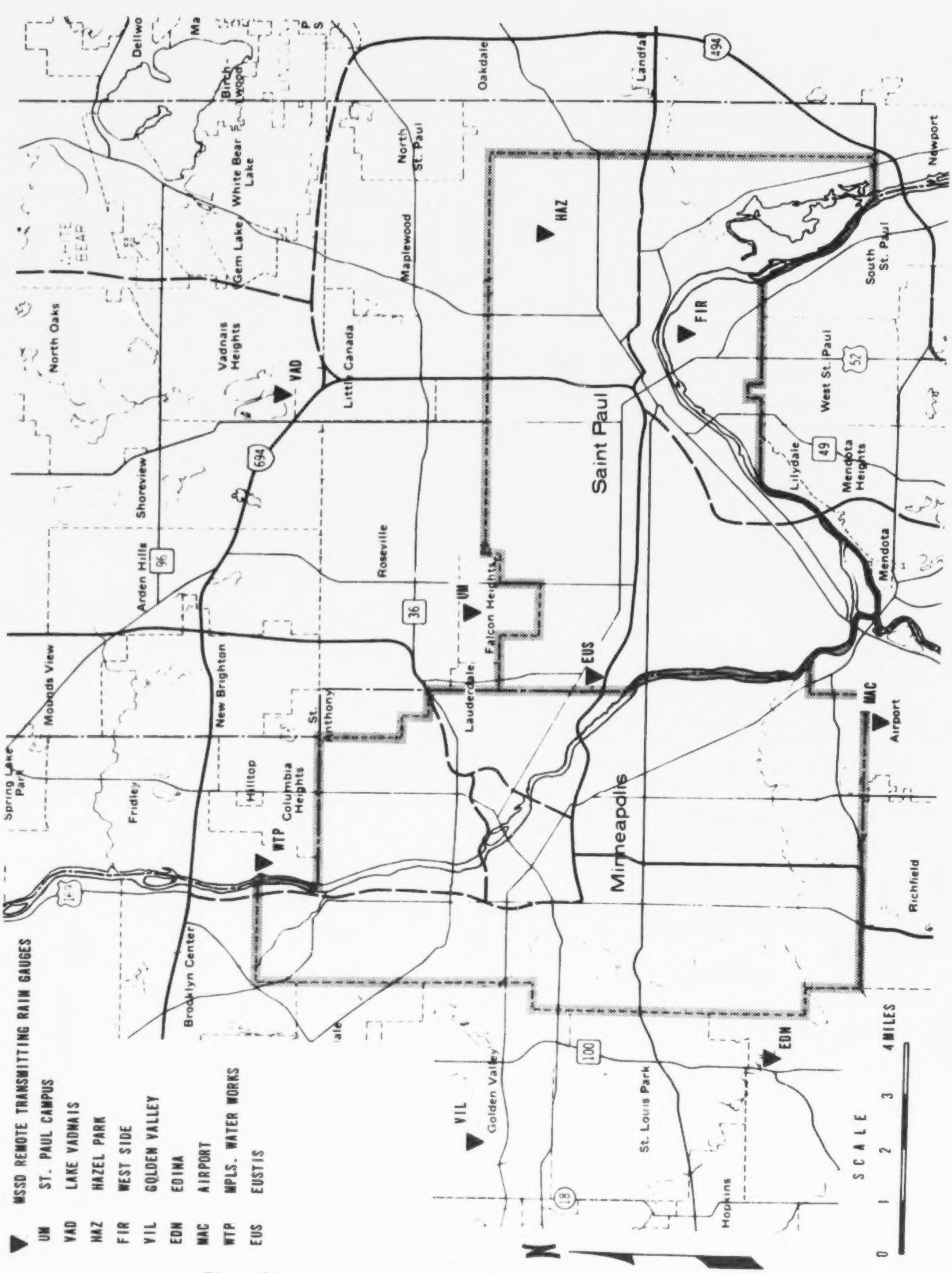
MSSD REMOTE TRANSMITTING RAIN GAUGES
UM ST. PAUL CAMPUS
VAD LAKE VADNAIS
HAZ HAZEL PARK
FIR WEST SIDE
VIL GOLDEN VALLEY
EDN EDINA
MAC AIRPORT
WTP MPLS. WATER WORKS
EUS EUSTIS
SCALE
0 1 2 3 4 MILES
N
Spring Lake Park
Mounds View
North Oaks
White Bear Lake
Gem Lake
Birchwood
Dellwood
Vadnais Heights
Shoreview
Arden Hills
New Brighton
Fridley
Hilltop
Columbia Heights
St. Anthony
Lauderdale
Falcon Heights
Roseville
Little Canada
Maplewood
North St. Paul
Oakdale
Landfall
Newport
South St. Paul
West St. Paul
Lilydale
Mendota Heights
Mendota
Saint Paul
Minneapolis
Airport
Richfield
Brooklyn Center
Golden Valley
St. Louis Park
Hopkins
694
494
96
36
49
52
100
18
UM
VAD
HAZ
FIR
VIL
EDN
MAC
WTP
EUS

Figure 25. Locations of the System's Nine Transmitting Rain Gages

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V. REGULATOR MODIFICATIONS

The largest design and construction job involved in the project was the revisions to the regulators. In addition to converting existing gates to remotely controlled power operation and installation of a variable position diversion device, there were some modifications to existing concrete structures to improve flow conditions. Before plans and specifications were completed, the Regulator Crew assisted the consultant's engineer and a testing laboratory in obtaining measurements of the forces required to move existing gates. Field measurements were taken and all the sites were inspected.

Contract 677

Contract 677 covered modifications to existing regulators and sewer structures. Work done included demolition of some existing structures and removal of existing equipment, concrete construction of new sewer structures and constructing and providing regulator gates and adjustable diversion devices with necessary fluid power systems for their operation. The adjustable diversion devices at all locations where required were inflatable dams under the base bid. Alternate bids were permitted for the adjustable diversion devices and either fabricated aluminum crest-type gates or wood fabricated rotating vane-type gates could have been bid. No bid on either alternate was received. Nineteen locations were involved in the work—eight in St. Paul and eleven in Minneapolis. Figure 26 shows the locations of modified regulators.

At the Camden regulator, (CAM), a side overflow weir was raised 1.1 feet and a new gate structure was constructed at the entrance to the outlet pipe leading to the interceptor. Two new fabricated wooden gates with oil hydraulic cyclinder operators were installed in the new chamber on the dry weather outlet and on the storm water bypass. Because the sewers have little cover there, an above-ground structure was necessary to enclose the hydraulic gate operators. The location is on Minneapolis Park Board property so an attractive structure was designed and built.

At Portland and Washington and at Second and Main, (PW and M2), the entire interceptors are diverted by master regulators. At these two locations and at 26th and Seabury, 39th and Minnehaha, 38th and Edmund, and Oak Street (SEA, M39, E38 and OAK, respectively), hydraulic operators were installed on the regulator gates and a rubberized fabric "Fabridam" replaced the existing weir.

At 31st Avenue N.E. and Randolph Street N.E. (RAN), a deformed corregated metal pipe had been placed in the invert of the existing trunk sewer as part of a Minneapolis sewer separation project. A Fabridam was installed here anyway since, under storm conditions, combined flow exceeding the capacity of the corrugated metal pipe occurred, and higher head conditions would increase diversion capacity.

Flow from each of the Minneapolis Interceptors is metered, primarily for purposes of cost apportionment. At all three interceptor meter stations, flow is measured by parallel Venturi meters. Two meters are in use at all times at the Southwest and East Interceptors. At the Northwest, prior to the Regulator Demonstration Program, only one Venturi meter was used. At each of the three structures overflow relief to the River is provided as well as by-pass gates. There were gates in the channels upstream from the Venturi meters at the Southwest and East also.

Bypass gates were installed in 1938 and were extremely difficult to operate. A full day was required to operate one gate using a large crew. As part of Contract 677, new bypass gates with hydraulic cylinder operators were installed. The gates were fabricated of creosoted wood with teflon bearing plates to decrease friction of the gate against the new aluminum guide channels.

New gates and guide channels were installed in the channel just upstream of the Northwest meters and the second, inactive Venturi meter was prepared for service. Figure 27 shows the two new gates at the Northwest Interceptor. Now more flow can be conveyed from the Northwest Interceptor to the inverted siphon river crossing during storm flow periods if there is capacity available downstream in the Joint Interceptor.

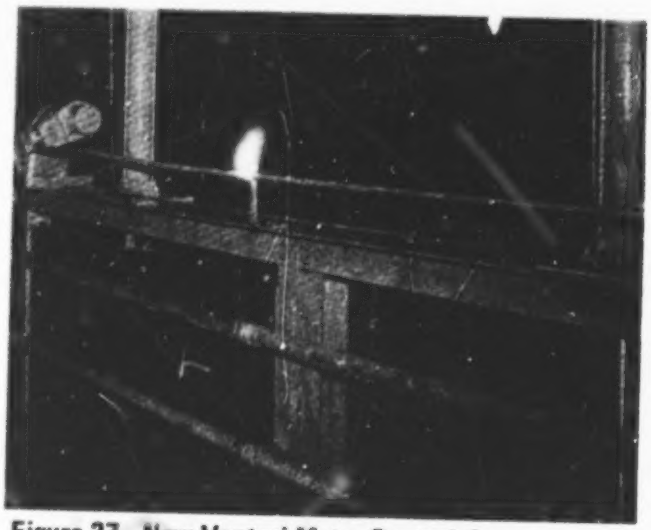

Figure 27. New Venturi Meter Control Gates at Minneapolis Northwest Interceptor

Modifications to regulators in St. Paul, in general, were more extensive. At the Rice-Rondo and Trout Brook regulators (RR and TB), the only modifications were the hydraulic gate operator and the Fabridam. The regulator gate and Fabridam at the Trout Brook

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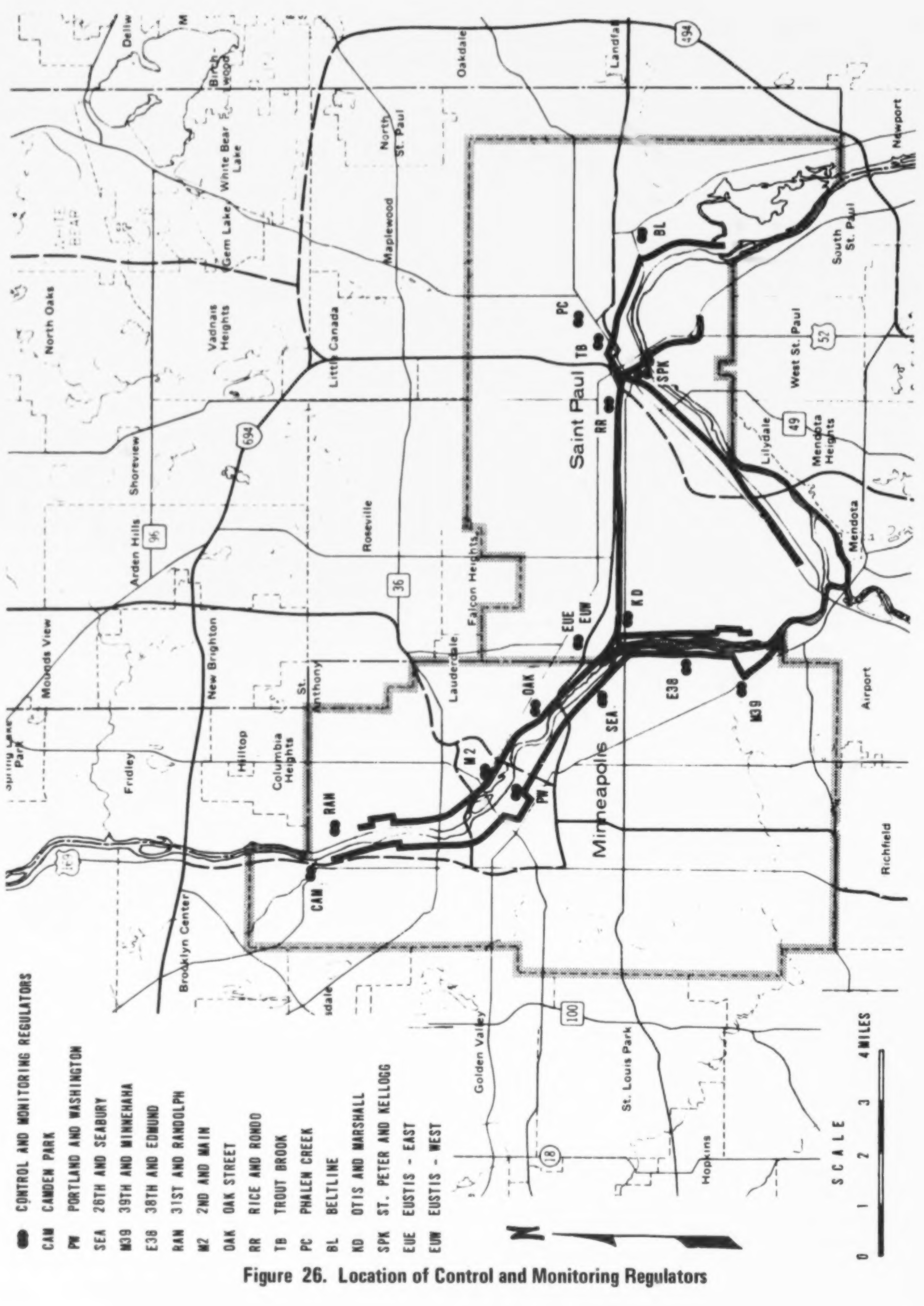
● CONTROL AND MONITORING REGULATORS
CAM CAMDEN PARK
PW PORTLAND AND WASHINGTON
SEA 26TH AND SEABURY
M39 39TH AND MINNEHAHA
E38 38TH AND EDMUND
RAN 31ST AND RANDOLPH
M2 2ND AND MAIN
OAK OAK STREET
RR RICE AND RONDO
TB TROUT BROOK
PC PHALEN CREEK
BL BELTLINE
KD OTIS AND MARSHALL
SPK ST. PETER AND KELLOGG
EUE EUSTIS - EAST
EUW EUSTIS - WEST
N
SCALE
0 1 2 3 4 MILES
Minneapolis
Saint Paul
CAM
RAN
PW
M2
OAK
SEA
E38
M39
EUE
EUW
KD
RR
TB
PC
SPK
BL
Brooklyn Center
Fridley
Hilltop
Columbia Heights
St. Anthony
Lauderdale
Falcon Heights
Roseville
New Brighton
Mounds View
Arden Hills
Shoreview
North Oaks
Vadnais Heights
Little Canada
Gem Lake
White Bear Lake
Birchwood
Dellwood
Maplewood
North St. Paul
Oakdale
Landfall
Newport
South St. Paul
West St. Paul
Lilydale
Mendota Heights
Mendota
Airport
Richfield
St. Louis Park
Golden Valley
Hopkins
Spring Lake Park
694
94
96
36
100
18
52
49

Figure 26. Location of Control and Monitoring Regulators

regulator are shown in Figure 28 and Figure 29. The gate is 32 inches wide and has a stroke of 21 inches. The Fabridam, installed in an old stone block sewer, has a height of 75 inches above the concrete base dam and is seen in this photograph from the back side, looking upstream. The air inflation pipe, seen along the left side of the photograph, disappears into the concrete base dam and enters the Fabridam near the center of its front attachment.

Figure 28. Hydraulic Power Operated Gate at the Trout Brook Regulator

Figure 29. Inflated Fabridam Diversion Weir at the Trout Brook Regulator

At the Phalen Creek regulator (PC) a new, enlarged regulator access chamber was constructed and in it a new gate and operator on the dry weather outlet was installed. In the trunk sewer a Fabridam was installed. A downstream secondary orifice regulator on the dry weather outlet pipe was eliminated, so a great improvement was made in the flow conveying structures. At this particular regulator, the outlet capacity is small in relationship to the flow arriving in the trunk sewer, especially in the summer months. Before modifications, dry weather overflow must have frequently occurred since, during 1969, high dry weather flow was completely diverted only when the Fabridam was fully inflated and a high head condition existed at the outlet pipe entrance.

At the Beltline regulator (BL), a new manhole was installed to permit installation of the Fabridam and the existing diversion channel was widened to improve flow conditions at the entrance to the outlet pipe. A new fabricated wooden gate and hydraulic operator were installed.

At the Otis and Marshall regulator (KD), a new power-operated gate replaced an existing regulator gate, the diversion tunnel was enlarged and a Fabridam was installed in the trunk sewer. Figure 30 shows the upstream side of the Fabridam in a view looking downstream. The opening to the dry weather outlet is visible on the right side of the Fabridam, which is 60 inches high. A power-operated gate is now used to control the flow.

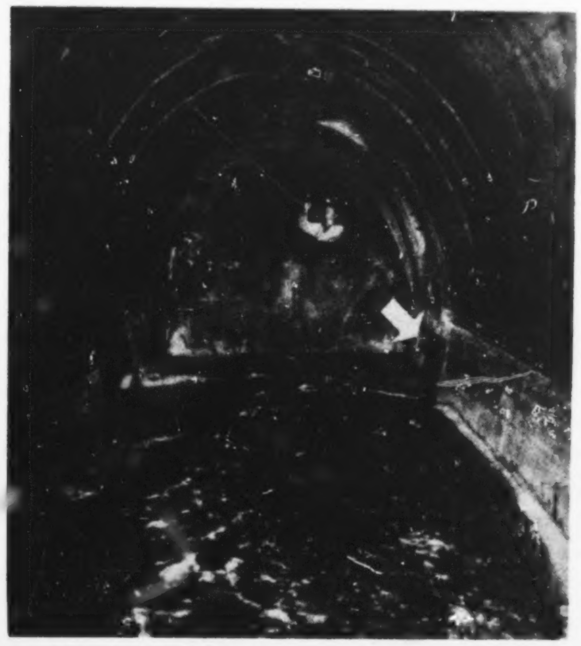

Figure 30. Inflated Fabridam and Dry Weather Outlet at Otis and Marshall Regulator.

At the St. Peter-Kellogg regulator (SPK), a Fabridam was installed and work done on a complicated regulator structure to improve its capacity. This included lining 73 feet of previously unlined tunnel and the removal of a cast orifice regulator. The Fabridam is pictured in Figure 31.

Figure 31. Inflated Fabridam at St. Peter and Kellogg Regulators

Wabash and Cromwell regulator (EUE and EUW) is a newly constructed regulator provided as part of a Storm Water Drainage project in St. Paul. Here two Fabridams were installed in each of two trunk sewers and equipment added to permit remote control as well as local automatic control of two existing pneumatic cylinder operated gates.

Table 7 summarizes the Regulator Modifications.

Table 8 is a tabulation of old diversion weirs and Fabridam data. In every instance, the fixed concrete base upon which the Fabridam rests is no higher than the old fixed height weir so that there is no uncontrolled loss of overall capacity to convey flow at any regulator.

Figure 32 shows package hydraulic pump units, commonly used in industry, which provide power for the cylinders which operate gates. These units are all the same size for easy replacement and maintenance. As a consequence the smaller gates can be quickly positioned and the larger gates move more slowly. Gate travel times for half stroke vary from 10 seconds to 10 minutes. The slowest operating gates are the bypass gates and Venturi channel gates at the Minneapolis meter structures. The hydraulic pump units are installed in the vaults serving the regulators and are connected to the gates in the sewers by stainless steel tubing.

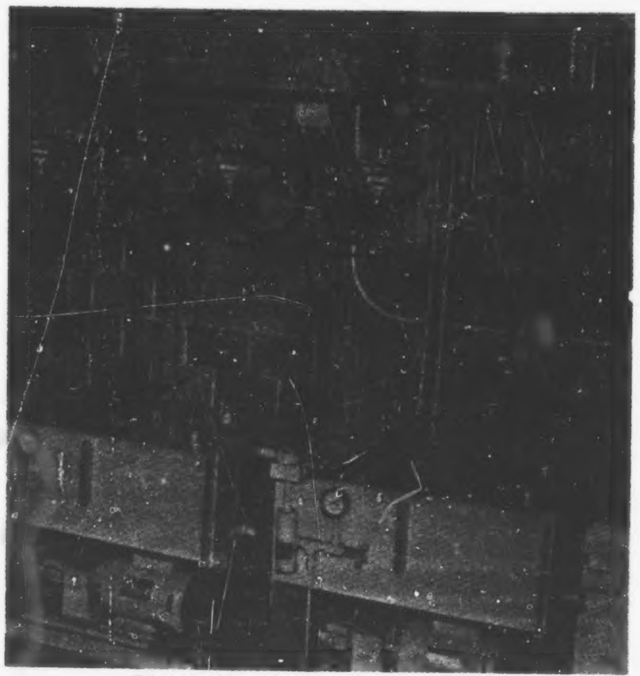

Figure 32. Hydraulic Power Units

Fabridam inflation is accomplished by small air blowers. The blowers used have a rated capacity of about 40 CFM when operated at 3000 rpm against two psi outlet pressure. For uniformity, interchangeability and ease of replacement and maintenance, all the blowers are identical although different pulley sizes were used at a few of the smallest dam locations to reduce blower speed and delivery. Inflation times vary from about four minutes to about eight minutes to bring a completely deflated dam to full inflation pressure. Most dams can be fully inflated in about five minutes. Recommended maximum working inflation pressures vary from 2.0 psi to 2.6 psi. The dams become quite rigid at much lower inflation pressures and under most flow conditions will function adequately at pressures around 0.5 psi.

The Fabridams are attached to the walls of the sewer and to the reinforced concrete base constructed on the floor of the sewer by rows of 12" long anchor bolts. Bolt diameter varies with the size of the dam; 3/4", 7/8" or 1" diameter bolts are used. The specification required by Firestone for these bolts is that the "anchorage develop the full strength of the bolt." Apparently this is quite important.

Post-Construction Evaluation

In June, 1968, less than a month after installation, one dam was badly torn during a rain storm when the fabric pulled from the clamping apparatus and caught the rushing flow of water like a sail. The center portion of the fabric was ripped on both sides from front to rear. If the original installation of the clamping apparatus was good, and Firestone is quite confident that the checking procedures used by the installer are adequate, then the probable cause of this was a slight

Table 7

TABULATION OF ADDITIONS AND MODIFICATIONS – CONTRACT 677

Location	REGULATOR GATES Number of Gates	Type of Gates	Size of Opening	Cylinder Stroke (Inches)	ADJUSTABLE DIVERSION DEVICE No. of Devices	Sewer Section	Maximum Width	Max.Height of Device Above Invert
Camden	2	New wood	4'0" x 5'0"	60"	None	Required	This	Location
	–	New wood	5'-0¼"x 4'0"	48"				
Portland & Washington	2	Exist.		28"	1	Arch.	7'-6"	5'-4"
	–	Exist.		28"				
26th & Seabury	1	Exist.		28"	1	Cir.	8'-0"	5'-4"
N.W. Meter	3	Exist.		66"	None	Required	This	Location
	–	New wood	7'-1½"x 7'0"	84"				
	–	New wood	7'-1½"x 7'0"	84"				
S.W. Meter	1	Exist.		78"	None	Required	This	Location
River Crossing	3	Exist.		60"	None	Required	This	Location
Outlet	–	Exist.		60"				
	–	Exist.		60"				
39th & Minnehaha	11	Exist.		16"	1	Horseshoe	11'-0"	6'-10"
38th & Edmond	11	Exist		16"	1	Cir.	10'-0"	6'-8"
31st & Randolph	None	Required	This Location.		1	Cir.	8'-6"	5'-8"
2nd & Main	1	Exist.		28"	1	Horseshoe	7'-0"	4'-8"
Oak	1	Exist.		16"	1	Cir.	8'-0"	5'-4"
E. Meter	1	Exist.		78"	None	Required	This	Location
Rice & Rondo	1	Exist.		Exist. 36"	1	Arch.	8'-0"	5'-6"
Trout Brook	1	Exist.		21"	1	Arch.	10'-0"	7'-0"
Phalen Creek	1	New wood	3'0" x 3'0"	33"	1	Semi-Elliptical	9'-3"	6'-3"
Belt Line	1	New wood	2'0" x 2'0"	24"	1	Transition	9'-0"	7'-8"
Otis & Marshall	1	New wood	3'0" x 3'6"	42"	1	Semi-Elliptical		
St. Peter & Kellogg	1	New wood	6'0" x 2'6"	72"	1	Transition	5'-11"	4'-8"
Wabash & Cromwell	2	Exist.		Exist. 36"	2	Square	7'-6"	5'-0"
	–	Exist.		Exist. 36"	–	Square	5'-0"	3'-4"

Table 8
TRUNK SEWER DIVERSION WEIR DATA

Location	Height of Pre-Project Diversion Weir	Height of Fixed Dam	Height of Fabridam	Section
Portland & Washington	3' 1½"	3' 1½"	2' 6"	Horseshoe 7'6" x 7'6"
26th & Seabury	2'	2'	3' 4"	Circular 8'0"
39th & Minnehaha	3' 6"	11½"	5' 10½"	Horseshoe 10'6" x 10'3"
38th & Edmund	2' 6"	2' 6"	4' 2"	Circular 10'0"
31st & Randolph	12"	12"	4' 8"	Circular 8'6"
2nd & Main	2' 2"	2' 2"	2' 6½"	Horseshoe 7'0"x 7'0"
Oak Street	3'	1' 3¼"	3' 7¾"	Circular 8'0"
Eustis–1	–	–	5' 3¼"	Square 7'6"
Eustis–2	–	–	3' 6"	Square 5'0"
Rice & Rondo	–	–	5' 6"	Horseshoe 8'0" x 9'6"
Otis-Marshall	1' 8"	12"	5' 0"	Semi-elliptical 8'2½"x 9'0"
Phalen Creek	3'	1.1'	5' 1-7/8"	Semi-elliptical 9'8-11/16"x 9'4-1/32"
Trout Brook	1' 8"	9"	6' 3"	Horseshoe 10'0" x 10'6"
Kellogg - St. Peter	1' 3"	1' 3"	3' 5"	Elliptical 5'8" x 7'2"
Belt Line	–	12"	6' 8"	Elliptical 9'0" x 11'7"

vertical movement of anchor bolts having inadequate anchorage which allowed the fabric to pull from the clamping apparatus. The anchor bolts were all removed and replaced before a new dam was installed. No further problems with this particular installation have occurred. During the spring and summer of 1969, three additional Fabridams were damaged after being released from the clamping. Two were damaged to the extent that replacement of the dam was necessary and one could be repaired and reinstalled. Testing of the anchor bolts confirmed that bolt withdrawal was likely the cause of the failures. The three dams were reinstalled during the spring of 1970 after all anchor bolts had been replaced.

Some of the Fabridams have developed air leaks that were not present immediately after installation. Some of these were caused by a small movement under the clamping bar. Repairs were made at two locations where this had occurred, but both dams later failed catastrophically, so it is safe to presume that the leaks had developed because of anchor bolt movement. Another leak that was fixed had originated at the location where the inflation air enters the dam. During installation, overly large bolt holes were cut in the fabric for the flange bolts and the holes elongated under fabric stress and produced leaks. This leak was repaired in May, 1969, and the air leaking almost stopped. Great care was taken on reinstallations to insure that bolt holes were cleanly cut to the minimum size so that this problem should not reoccur. The installer provided by Imbertson and Associates, Inc. of Burbank, California, engineers for the initial Fabridam installations, is no longer employed by them.

Revisions to the clamping apparatus have been suggested by Firestone and Imbertson that should make installations somewhat less dependent on strength of bolt anchorage. The revision would permit clamping together the top and bottom clamping bars separately from the anchorage of the clamping bars to the sewer. This should provide more uniform clamping pressures as well as reduce the likelihood that a small movement of an anchor bolt would result in catastrophic damage to the fabric dam.

Inspection of several dams has revealed no discernable deterioration of the rubberized fabric material after about two years of service in the sewers. Although there have been some problems, the local contractor and Firestone have been cooperative in correcting problems at no cost to the Sanitary District. The Sanitary District's Regulator Crew provided most of the labor, under the supervision of the contractor and the Imbertson installer, for the reinstallation of three Fabridams in 1970, however. The experience gained by them has increased their ability to handle maintenance of the Fabridams in the future.

The original installation of the Fabridams included no provision for draining water from the interior of the dam. Water can enter through punctures or other wounds to the fabric, through leaks or breaks in the inflation pipe, by leaking through the attachment, and by condensation. The first problem with water was encountered following repair of a section of inflation pipe that was torn out during a rain storm. After the repair, the dam could be inflated, but not deflated, because the water in the dam could rise in a vertical leg of the inflation pipe until the column of water was equal to the inflation pressure in the dam. Rather than pierce the fabric to install a drain, a "Y" fitting was installed near the point where the inflation pipe enters the concrete base under the Fabridam. With a plug in the "Y" the dam can be inflated and then, when the plug is removed, the air pressure in the dam forces the water out. Several inflation-deflation cycles have been sufficient to remove almost all the water from a dam and restore deflation control. The extra fitting was installed on all the Fabridam inflation pipes so dewatering can easily be accomplished. This also permits deflation of the dam without requiring operation of the solenoid valve in the vault.

In addition to the blower, there are several other devices installed in the vaults to control and protect the Fabridams. Figure 33 shows the control valves and piping at the blower. A one-inch normally closed solenoid valve is used to control deflation. The valve can be energized and opened locally or remotely via the telemetry system. A one-half inch normally open solenoid valve will cause the dam to deflate automatically upon power failure to insure that, if control is lost, the dam will be in the safest position. A pneumatic check valve prevents air flow back through the blower. The dam must be protected against over-pressurization, apparently to avoid damage. A spring-loaded pressure relief valve was provided to allow air release when pressure exceeds a set limit. These valves have not been very reliable. Once opened, they tend to remain cracked open slightly and do not always seal after pressure has been relieved. They apparently do not provide fast enough pressure relief either.

A final precautionary device to prevent overpressure is a water column whose height equals the maximum allowable internal pressure. Ostensibly the water column was intended to be a redundant device. However, it was found that severe storms did occasionally cause Fabridam pressure to be relieved by the water column rather than by the mechanical valve. Air entering at the base of the column forms a piston which discharges most of the water from the top of column quite suddenly, and then the dam deflates entirely. The dam cannot then be reinflated until the column is again filled with water. This has happened frequently on only a few dams but is a disadvantage since post peak runoff often could be diverted if the dam could be reinflated. On two locations where this has occurred, a pressure switch has been installed which, when pressure in the pipe terminated in the water column exceeds a set value somewhat less than the height of the water column, will energize and open the solenoid valve until the pressure is relieved. Since this more positive acting pressure relief measure has been in use, several rainstorms have occurred during which pressure relief was adequate and the column not discharged. Pressure switches will be installed at other locations where the water column emptying has reduced the effectiveness of the system. Another measure that could be taken would be to replace the 4-inch diameter water column with a larger one through which air could be discharged without causing the column to be emptied.

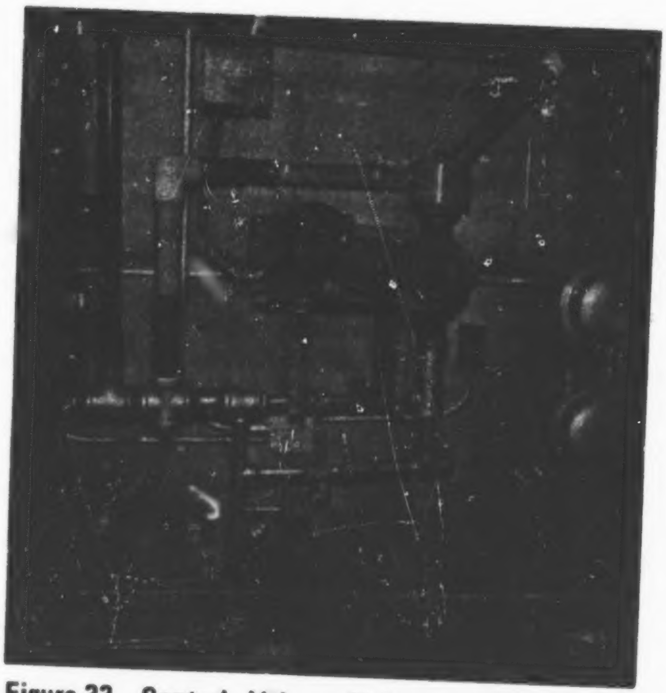

Figure 33. Control Valves, Piping, and Blower for Inflatable Dam

A pressure sensing line runs inside the 1-1/2" or 2" inflation pipe into the interior of the dam. This pressure is supplied to a pressure switch installed in the electrical circuit which operates the air blower. The switch is set to open the circuit and stop blower operation when pressure in the dam reaches a set limit. The use of the tubing permits the blower to be controlled by a near static air pressure because of the large volume in the dam.

The original installation of the Fabridams did not provide any means of determining remotely the internal pressure. Sanitary District personnel later obtained and installed pressure transducers which enable the dam inflation pressure to be monitored. Small film type potentiometers manufactured by Computer Instruments Corporation were used and have been found to be extremely reliable.

All the piping appurtenant to the inflatable dams is PVC plastic. There has been no real disadvantage to its use except that the portions installed in the sewer have been damaged and torn out at two locations. This has not recurred since reinstallation included protection from debris carried by storm flow. The use of securely anchored metal pipe would probably have made this protection unnecessary. The inflation pipes enter the concrete base dams on their downstream sides so that they are protected by the dam except under severe storm flow conditions. This also permitted the work to be done on the dry side of the dam during installation.

Tank gages are used to measure gate position. Gate movement produces a shaft rotation into a sealed potentiometer which transduces gate position into an analog voltage. Several of the gages have been removed for cleaning and several potentiometers have been replaced. The service is severe, however—several can be submerged during rainstorms—and this maintenance should probably be expected.

VI. PROCESS CONTROL AND COMMUNICATIONS EQUIPMENT

Processing System

Specifications were prepared by Pioneer Service and Engineering Co. for "Installation of Air Pressure Transducers, Telemetering and Supervisory Control Equipment, and Computer–Contract 664B."

The system described in the specifications had to be capable of collecting, processing and logging data on sewer flow, gate status, rainfall and river quality. Data from remote station instruments was to be input to a computer, scaled to engineering units and logged both as a printed record and in machine processible form. Provision for controlling gates at remote stations was also required. Computer time had to be shared for logging treatment plant data. The computer had to be capable of performing other computations during its idle time in addition to the primary on-line functions. In other words, the computer was to be provided with foreground-background time sharing capabilities. The requirements were essentially for a computer-based supervisory control and telemetering system.

Specifically, the work under this Contract 664B consisted of furnishing and installing 44 pressure transducers, telemetering equipment for 38 remote stations, supervisory control equipment, and a computer with certain peripheral equipment. The contractor was responsible for the compatibility and operation of the complete system from pressure transducer to and including the computer and computer logging.

Bids were received from Badger Meter Manufacturing Company, The Bristol Company, General Electric Company, Automatic Electric Company, Control Data Corporation and CAE Industries. The contract was awarded to the low bidder, Badger Meter Manufacturing Company.

Certain optional alternates were bid and during contract negotiations the following were approved:

1. Substitution of a Potter Chain printer for one output typewriter.
2. Addition of 8000 words to the core memory to increase its size to 16K.
3. Substitution of a disk file for a Random access memory file.

Later by change order, two other items were added to the contract. One was the inclusion of an operator's panel for the out-plant sewer control system. This panel would allow manual addressing, remote operation of gates, and monitoring of outplant data even though the computer might be out of service. The operator's panel was also of value for maintenance and checkout purposes. The other item was the inclusion of two DEC TC02 magnetic tape transports. This provided a more reliable system, backup mass memory in case of problems in the disc file, and easy exchange of manufacturer prepared programs. Both have proved to be very valuable additions.

The digital computer used with the system is a PDP-9 manufactured by the Digital Equipment Corporation. The PDP-9, pictured in Figure 34, is a single address, 18-bit word length, parallel binary computer. It is a completely self-contained machine, not requiring special air conditioning or humidity control. The central processor's core memory has a 1.0 micro second cycle time. Originally the PDP-9 used had 16,384 words; the core memory size was later increased to 24,576 words as part of an agreement modifying the contractor's software obligations.

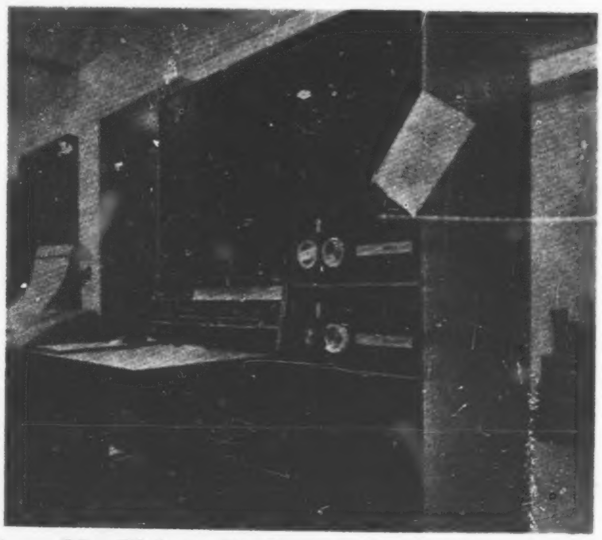

Figure 34. Digital Equipment Corporation PDP-9 Computer

The standard PDP-9 I/O facilities include a 300 character-per-second paper tape reader, a 50 character-per-second paper tape punch and a 10 character-per-second console teleprinter. In addition, the Minneapolis-Saint Paul Sanitary District system has a high speed disk, two magnetic tape drives, a line printer, two additional console teletypewriters and a logging teletype.

The magnetic tape system, called DECtape, employes small reels of 3/4", 1 mil mylar sandwich tape with an information capacity of 2.7×10^6 bits per 260 foot reel.

The disk storage drive is a Control Data 853, shown in Figure 35. This disk drive uses industry standard removable disk packs. Each disk pack has six disks with ten usable disk surfaces and 100 tracks per surface. The total capacity per disk pack is 24,576,000 bits or 1,365,333 18-bit words. The maximum one-track access time is 30 milliseconds.

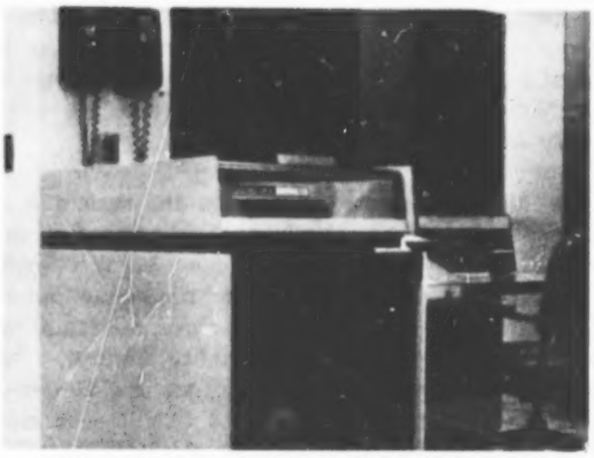

Figure 35. Control Data 853 Disk Drive

The line printer, Figure 36, is a Potter HSP-3502 Chain Printer having a printing speed of 315 lines per minute. Its features include 132 character output per line and reformattable page control.

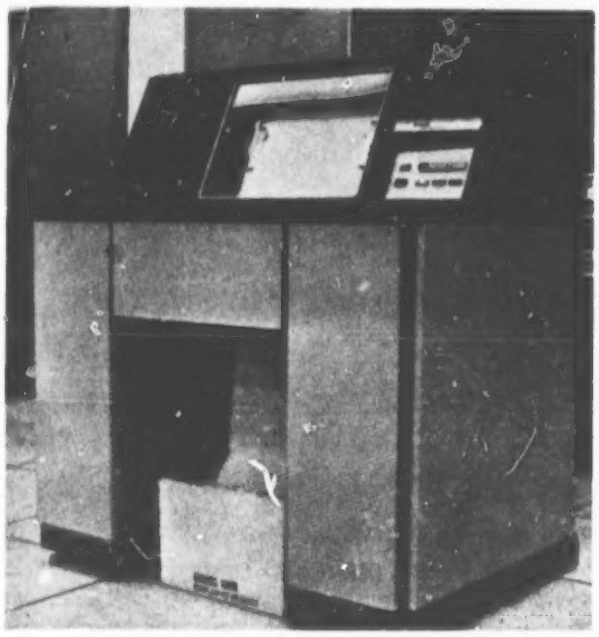

Figure 36. Potter Line Printer

The teletypewriters on line with the system are standard ASR 33 and ASR 35. Both types employ the 10 character-per-second output and compatible interfacing. The ASR 35 is simply a heavy duty model of the ASR 33 which enjoys longer life and quieter operation.

The controllers and special hardware requirements were designed and built specifically for the Minneapolis-Saint Paul Sanitary District's system. The disk controller, provided by Digital Logic Corporation as a subcontractor of Badger Meter Manufacturing Company, caused serious problems for a while but since being revised has been highly dependable. Other interfacing was accomplished by Badger Meter. This included the line printer handler, the operator's control panel, digital displays, and strip chart recorders, all mounted in a single interface cabinet, Figure 37, along with the disk controller and the base station telemetry equipment.

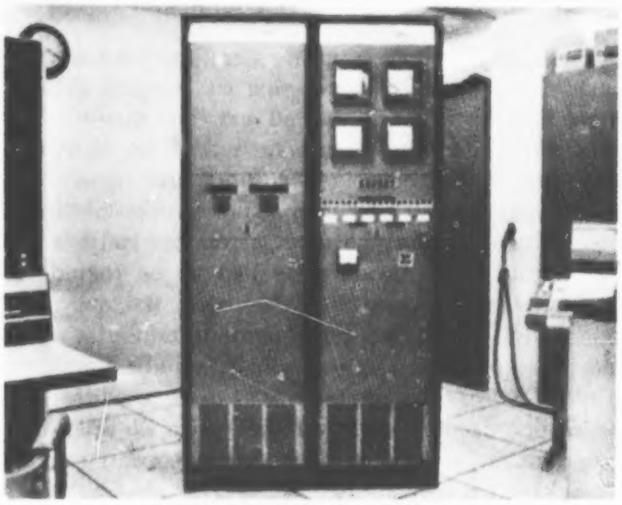

Figure 37. Interface Cabinet

The software requirements were to be met by the systems library software developed by the computer manufacturer, by special programs supplied by the contractor, and Sanitary District prepared programs. Digital Equipment Corporation's standard software package for the PDP-9 is called Monitor V4B. Its features include:

1. ASA FORTRAN IV
   This compiler meets all ASA specifications and standards.
2. MACRO-9
   A basic assembler language comparable to BAL (IBM's processors) or OSAS (CDC's processors)
3. PIP
   Peripheral Interchange Program for manipulation of data files and programs.
4. EDIT
   Systems program used in program preparation and modification.
5. DDT9
   Dynamic Debugging Technique. A modified loader which can debug a user's program while in operation.
6. LINKING LOADER
   A program which loads any absolute or relocatable user program and all called subroutines.

As special options, the PDP system also has:

Extended Arithmetic Element
Memory Extension Control

Power Failure Protect
Memory Protection
Automatic Priority Interrupt

In addition to its program library, the Sanitary District has had access to all other services extended by DECUS the Digital Equipment Corporation Users Society. Project personnel have attended technical and educational meetings held by DECUS. Additional software for the PDP-9 is automatically received as it is entered into or updated by the DECUS library.

Badger Meter Manufacturing Company was to have provided an executive time-sharing routine, operator Input/Output routines and other programs for trend recorder selection and output, acquisition of outplant data, and gate selection and control. The Sanitary District was to supply the real time programs for scanning, scaling data and logging data, obtaining the data from contractor supplied subroutines.

The original FWPCA project termination date was July 1, 1969, with the year of operation for evaluation complete in 1968. When it was realized that Contract 664B would not be completed in time to start system operation during 1968, the Sanitary District applied for and received from the FWPCA a project time extension of one year with no increase in project funding. This meant that operation had to begin in the spring of 1969. In January, 1969, the Project Engineer felt that the best interests of the Sanitary District and the FWPCA required that Badger Meter Manufacturing Company's work toward meeting the requirements of Contract 664B be interrupted so that the system could be prepared for operation during the 1969 rainfall season. The contractor's efforts at this time were largely directed, through a subcontractor, toward completion of the executive time-sharing software. Provisions of the contract clearly permitted the Sanitary District to take this action. The contractor, with the understanding that it would be provided a further opportunity to complete its obligations when the system's utilization was less critically needed, cooperated by providing system maintenance and support.

Fortunately, almost all of the system was usable and the Sanitary District was able to prepare programs in time to operate in 1969. The system was operated as a dedicated system and could not, while scanning, be utilized further.

In May, 1969, negotiations began regarding completion of remaining contract obligations by Badger Meter Manufacturing Company. By this time, operating programs for the system had been prepared and most of the system hardware had been successfully used. The contractor proposed to complete all unfinished hardware related work and have separate hardware acceptance testing as the criterion for hardware acceptability. They also proposed that a soon-to-be-released DEC foreground/background monitor system would be better for the Sanitary District than the still not completed executive time-sharing routines. All programming by the Sanitary District since January had utilized the current DEC monitor system so the use of DEC's foreground/background monitor had definite advantages. The proposal also included additional hardware items, another I/O teletype with associated logic and 8,000 words additional core memory, and cash contribution toward writing the handlers and making other modifications required to adapt the DEC monitor for use on the Sanitary District system.

On October 15, 1969, an agreement between the Minneapolis-Saint Paul Sanitary District and Badger Meter Manufacturing Company was signed. Essentially the agreement relieved the contractor of the software obligations in Contract 664B in exchange for the additional hardware and cash contribution toward adaptation of the DEC foreground/background system. Subsequently, the contractor returned, completed unfinished hardware work and obtained complete hardware acceptance. The Sanitary District received a preliminary foreground/background monitor system from DEC and had its systems consultant begin writing necessary handlers. At the time of writing, June, 1970, the general and complete foreground/background monitor had not been released by DEC. This release is anticipated soon. Based upon experience gained using the preliminary version, it is expected that only a few months will be required to implement the foreground/background time-sharing system once the finished version is received.

Leased Line System

The telemetry equipment provided under Contract 664B to permit information to be returned from the outplant sites and control to be exercised from the central station is dependent upon a system of leased telephone lines as the medium of communication. Fairly early in the project a meeting was held between representatives of Northwestern Bell Telephone Company, Badger Meter Manufacturing Company and the Sanitary District. It was agreed that seven circuits leading to the central station would result in the best application of the communications equipment. The telephone company would in the leased lines incorporate high impedence bridges with sufficient gain added to make the lines appear as an 8 db loss at 1,000 cps. The frequency spectrum to be used for the communications system was 400 to 2700 cycles per second. Figure 38 shows the leased line arrangement.

Northwestern Bell Telephone Company began work on providing the leased lines in December, 1967. Many of the circuit drops were made by January but not without problems and much communication between Sanitary District and telephone company personnel. Many of the remote sites were underground vaults, some at sites not easily described. The river monitors

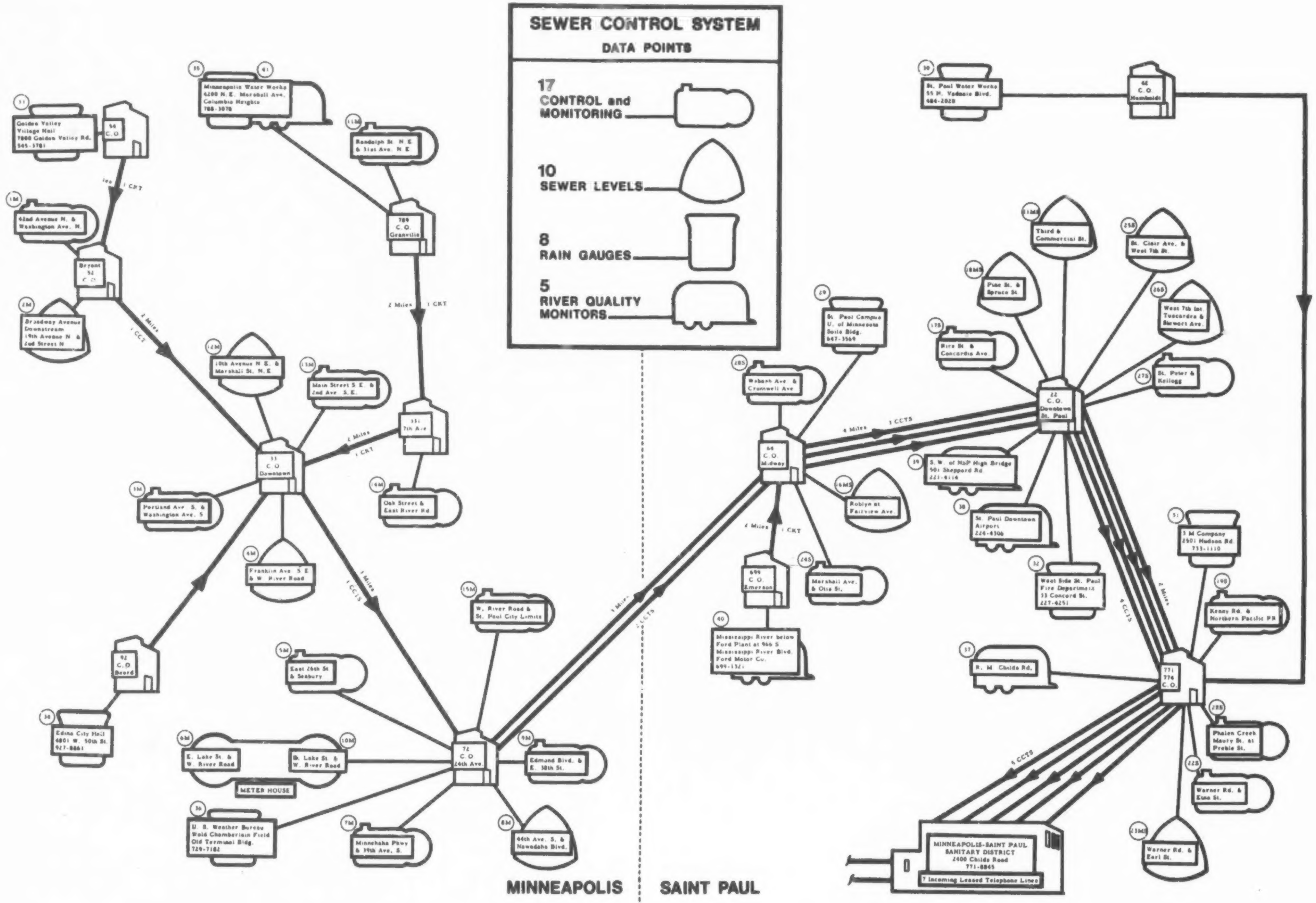
SEWER CONTROL SYSTEM
DATA POINTS
17 CONTROL and MONITORING
10 SEWER LEVELS
8 RAIN GAUGES
5 RIVER QUALITY MONITORS
MINNEAPOLIS
SAINT PAUL
31
Golden Valley Village Hall 7800 Golden Valley Rd. 545-3781
54 C.O
1 CKT
1M
42nd Avenue N. & Washington Ave. N.
Bryant 52 C.O
2M
Broadway Avenue Downstream 19th Avenue N & 2nd Street N
2 Miles
1 CCT
35
41
Minneapolis Water Works 4200 N.E. Marshall Ave. Columbia Heights 788-3078
11M
Randolph St. N.E & 31st Ave. N.E
789 C.O. Granville
2 Miles
1 CKT
12M
10th Avenue N.E. & Marshall St. N.E
13M
Main Street S.E. & 2nd Ave S.E.
331 7th Ave
2 Miles
1 CKT
33 C.O Downtown
14M
Oak Street & East River Rd
3M
Portland Ave. S. & Washington Ave. S
4M
Franklin Ave. S.E & W. River Road
3 Miles
1 CCTS
92 C.O Beard
34
Edina City Hall 4801 W. 50th St. 927-8861
15M
W. River Road & St. Paul City Limits
5M
East 26th St & Seabury
6M
E. Lake St. & W. River Road
10M
B. Lake St. & W. River Road
METER HOUSE
72 C.O 24th Ave.
9M
Edmond Blvd. & E. 38th St.
36
U.S. Weather Bureau Wold Chamberlain Field Old Terminal Bldg. 729-7182
7M
Minnehaha Pkwy & 39th Ave. S.
8M
44th Ave. S. & Nawadaha Blvd.
1 Miles
2 CCTS
29
St. Paul Campus U. of Minnesota Soils Bldg. 647-3569
28S
Wabash Ave. & Cromwell Ave.
64 C.O. Midway
4 Miles
3 CCTS
16MS
Robyn at Fairview Ave.
2 Miles
1 CKT
699 C.O. Emerson
24S
Marshall Ave. & Otis St.
40
Mississippi River below Ford Plant at 966 S Mississippi River Blvd. Ford Motor Co. 699-1321
30
St. Paul Water Works 55 N. Vadnais Blvd. 484-2020
42 C.O Humboldt
21MS
Third & Commercial St.
25S
St. Clair Ave. & West 7th St.
18MS
Pine St. & Spruce St.
26S
West 7th Int. Tuscarora & Stewart Ave.
17S
Rice St. & Concordia Ave.
27S
St. Peter & Kellogg
22 C.O. Downtown St. Paul
39
S.W. of NSP High Bridge 501 Sheppard Rd 221-4114
38
St. Paul Downtown Airport 224-4306
32
West Side St. Paul Fire Department 33 Concord St. 227-6251
2 Miles
4 CCTS
31
3 M Company 2501 Hudson Rd. 733-1110
19S
Kenny Rd. & Northern Pacific PR
37
R. M. Childs Rd.
771 774 C.O.
5 CCTS
28S
Phalen Creek Maury St. at Preble St.
22S
Warner Rd. & Etna St.
23MS
Warner Rd. & Earl St.
MINNEAPOLIS-SAINT PAUL SANITARY DISTRICT 2400 Childs Road 771-8845
7 Incoming Leased Telephone Lines

Figure 38. Schematic Diagram of Outplant Stations and Leased Line System

were not in place by that time so completion of some of the circuit legs had to be delayed. Rain gages were located near public buildings and the locations of the telemetry equipment located in any available space in the nearby structures, which sometimes caused complications. Street addresses were used to help locate the various remote stations, but calls from telephone company personnel asking questions such as, "Are you sure you want this circuit terminated at the shoe store?" were not uncommon.

After the circuits had been physically prepared, they were tested for attenuation losses at various frequencies and corrections were made where required. Progress was somewhat hindered by a strike of telephone company workers from April 18 to May 6, 1968. Since telephone company work preceded the installation of communications equipment in the field by Badger Meter Manufacturing Company, some equipment connections were not made until the first part of June, 1968, because the telephone company had to extend their lines from one termination point to another within reach of our equipment.

Installation charges for the seven leased line circuits service 37 outplant sites were $1,000. The monthly charge for the seven circuits is $548.

Communications System

Part of Contract 664B called for provision of a communications system consisting of supervisory control and telemetering equipment. The supervisory control equipment permits sequential selection, interrogation, and verification of remote station transducer signals for connection to telemetering channels and also control of gates at remote stations in the system. The telemetering equipment transmits data from the remote stations to the central control station where analog to digital interface conversion permits data input to the computer.

The air pressure transducers provided are Robertshaw Model 115 Microsen Pressure Transmitters which, by means of a bellows pressure element, convert air pressure to an analogous 4 to 20 milliamp signal. Forty-two pressure transducers in ranges of 0-40", 0-72", 0-120", and 0-144" of water are used, and one spare in each range was supplied.

The supervisory control and telemetering equipment is that manufactured by Noller Control Systems, a wholly owned subsidiary of Badger Meter Manufacturing Company.

The remote station telemetering equipment had to transmit data from the pressure to current transducers and from rain gages, gate position transducers and river monitors. At the present time there are 139 unique addresses from which information can be obtained.

Remote station addresses are three or four digit octal numbers which in binary form a selection code indicating which of the seven leased telephone lines is to be accessed, which group of two transmitters the central station will use, and which of three possible states each of the two transmitters will be in. Table 9 shows the numbers of points of each description.

Table 9

NUMBER OF MEASUREMENT AND CONTROL FUNCTIONS

Function	No. of Locations	No. of Points
Level Measurement—Interceptor Sewers . .	12	12
Level Measurement—Trunk Sewers	15	18
Level Measurement—Outlets to Interceptors	12	12
Gate Positions and Controls	17	34
Rain Gages	9	9
River Quality Monitors	5	30
Alarms and Spares	18	24
	(a)	139

(a) Total number of locations of telemetry equipment is 37 due to overlapping functions at certain stations.

The remote stations are of two types insofar as the telemetry equipment is concerned. One type has only a single point such as an interceptor monitoring station or a rain gage. The other type has up to eight points at a single location, although most have only five. At the single point stations only a single receiver and transmitter are used to complete the unique point address and produce a "confirmation" code back that verifies selection of the proper point. The other stations employ a pair of receivers and transmitters. Transmitters are three-state frequency-shift devices, so the pair arranged as a three by three matrix can produce nine possible combinations. One combination is not used, so a pair of tone transmitters and receivers can be used for up to eight points. Data transmission is analog. Transducers produce or have signals conditioned to 0 to 5 volt analogs, which are converted to pulses, and then to a frequency-shift keying tone transmitter signal. Central station receiving equipment reproduces the direct current transducer signal. All components are self-contained on circuit boards which are edge mounted in card cages.

The Sanitary District has been able to maintain the operation of the telemetry system without assistance for over a year now. A short period of instruction was provided by the contractor and initial checkout and adjustments accomplished by him.

Some spare components have been bought to assist in maintaining continuous operation from all outplant stations. MSSD has not yet performed repair of any components; components replaced because of problems have been sent to Badger Meter Manufacturing Company for repairs.

MSSD has found that maintenance of the communications system involves more than the ability to maintain one's own equipment. It has been helpful to be able to define telephone line problems to some extent when reporting such problems to the telephone company. All complaints regarding telephone lines are handled at the closest exchange to the central station. This has worked well since only a single person need be contacted rather than someone at each of the many telephone central offices involved in the system. Some special equipment has been required to assist in maintaining the communications system. Two frequency selective voltmeters, two AC voltmeters and two electronic counters, one each for the remote site mobile maintenance vehicle and for the central station, were obtained.

Maintenance of the system has been under the direction of the Project Engineer who has also handled the central station end of many calibration and troubleshooting operations. The outplant end has been handled by the electrician assigned to the project. Other plant electricians have been trained, and the maintenance electricians are now able to handle the communications equipment alone.

Periodically, perhaps two or three times per year, adjustments in tone transmitter and receiver sensitivity levels may be required to maintain the proper levels and operating margins. This is necessitated by seasonal variations in the characteristics of the leased telephone lines.

Calibration Procedures

The use of a computer with the data logging system makes calibration simple. All calibrations are from the input to the primary sensing element to the scaled value in engineering units appearing on the printed page. An example of a calibration is cited: Personnel who have reached the remote site to be calibrated contact someone at the central station via radio. At the central station, the calibration program, named CHKOUT for CHECKOUT, is called. This program samples the A/D output and calculates the analog voltage equivalent and prints this voltage on the I/O teletype. At the remote site, a hand-operated pressure calibrator is used to apply various levels of pressure to the pressure transducer. The corresponding voltage is measured at the central station for each pressure. Figure 39 illustrates the teletype commands used in calibrating, with the CHKOUT program. A linear scaling equation is then calculated from the pressure-voltage data. The same technique is used for the inflated dam pressure transducer. Voltages corresponding to gate position are read also. With this data, which can be obtained in a matter of minutes, four scaling equations are calculated and entered into the appropriate reference list to complete calibration of the control and monitoring station.

Other stations are calibrated similarly. Rain gages are calibrated using one-inch equivalent weights. River monitors are calibrated using the ambient reading observed at the local readout meters and the zero point for each parameter. All calibrations are periodically checked to see if scaling factors need to be updated.

```
↑C

MONITOR V4B                    (Operator types in request for
                                CHKOUT program)
$E CHKOUT



ADDRESS-(XXXX)         (Address 1307 is the regulator gate
                        at 39th and Minnehaha)
1307

FACTORS-(XXXX.XXX XXXX.XXX)
                                (Factors used only when
                                 scaled values are to be
                                 reported)

1307 2.845    0.000
ADDRESS-(XXXX)                 (0% open - transducer
                                output is 2.845 volts)
1307

FACTORS-(XXXX.XXX XXXX.XXX)


1307 2.845    0.000
ADDRESS-(XXXX)




1307

FACTORS-(XXXX.XXX XXXX.XXX)


1307 4.640    0.000            (100% open - transducer
ADDRESS-(XXXX)                  output is 4.640 volts)

1307

FACTORS-(XXXX.XXX XXXX.XXX)


1307 4.640    0.000
ADDRESS-(XXXX)
```

Figure 39. Calibration of an Outplant Address using the CHKOUT Program

Inplant Data Acquisition System

Unrelated to the Regulator Demonstration Program, but included in Contract 664B, was computer capability and equipment to permit plant monitoring and data logging for certain parameters in the sewage treatment plant as a secondary priority function. This includes a station located in the Plant Operators' office where plant data can be displayed and logged. The system provided is hard-wire with all of the analog signals wired directly to the interface equipment. One combination of the three most significant bits of the computer buffer register and the nine least significant bits is used for address codes for the inplant data inputs. The output buffer register is decoded using binary to octal decoders to give 241 individual address signals which control 241 reed relays which switch the various analog signals into the A/D converter. The common input channel for the thermocouples is a thermocouple wire referenced to a cold junction and fed through a high gain amplifier and then to an A/D converter. All other input signals are conditioned to a standard DC signal before being switched into the common input channel to the A/D converter.

The hardware provided has been tested and accepted but little use of the plant data logging capabilities has been made to date. It is expected that during 1971, after the new time-sharing monitor system has been implemented, the inplant data logging programs will be prepared.

The equipment located in the Plant Operator's office—the ASR35 logging teletypewriter, the ASR33 I/O teletypewriter, and the inplant interface cabinet—is shown in Figure 40. The strip chart recorders can be assigned to either inplant or outplant points. Also mounted in the cabinet are receivers used to present telemetering data from the existing interceptor and plant flow meters to the computer.

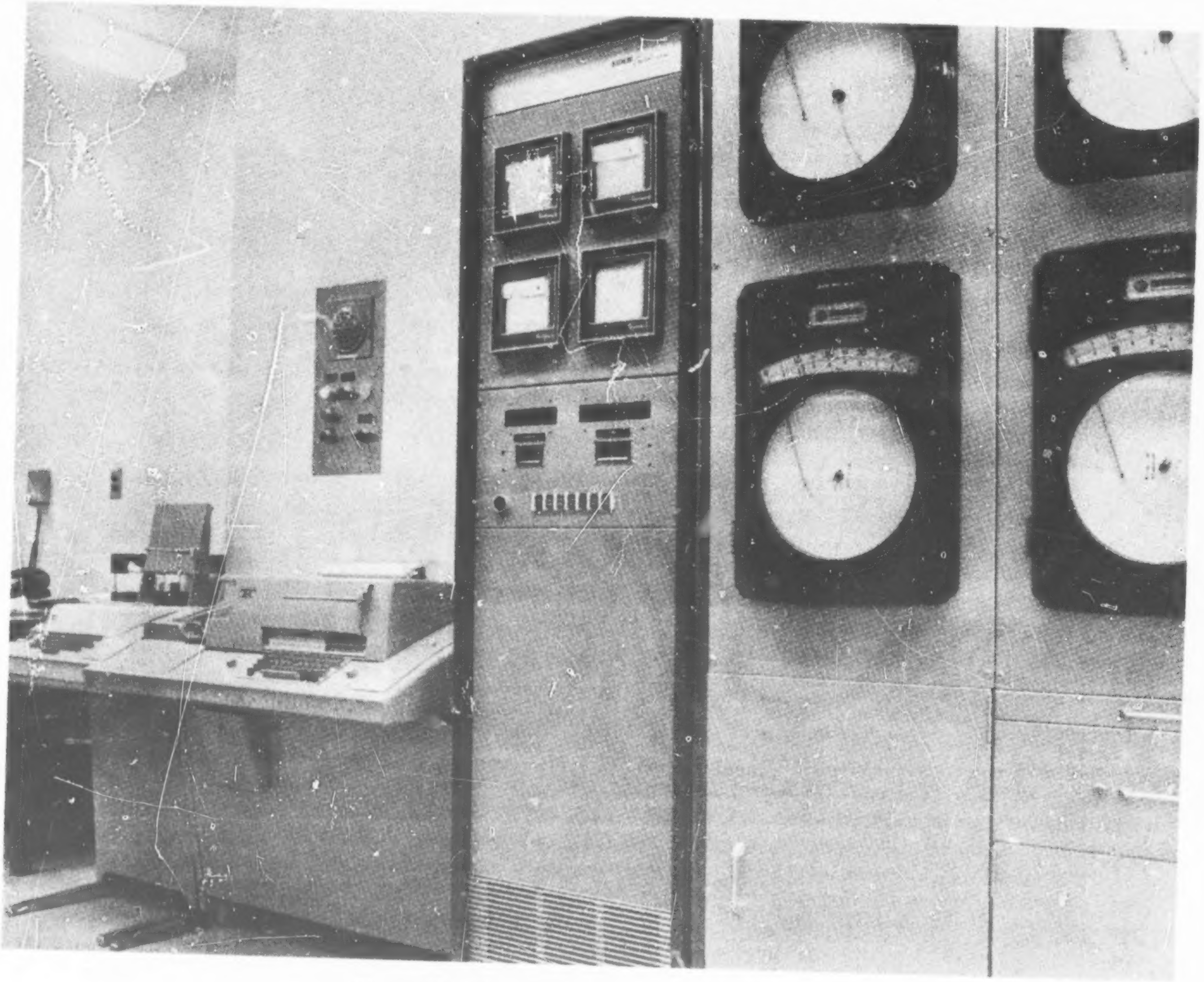

Figure 40. Plant Operator's Logging Equipment

VII. RIVER MONITORING

Since there has only been intermittant sampling of Mississippi River water in the metropolitan area at frequencies varying between once per week and once per month, with no consideration given to time of occurrence of rainfall, it was felt that the effects of sewer overflows were really unknown. To assist in making an evaluation of the effects of combined sewer and storm sewer overflows, five river quality monitors were acquired and sited to intensively monitor the urban stretch of the river most affected by sewer overflow.

Site Selection

In selection of sites, several factors were taken into consideration. First, the general locations had to be chosen such that the intention, measuring the extent to which the river is affected by overflows, could be accomplished. A monitor upstream of most of the metropolitan area, particularly upstream of any combined sewer outfall, was necessary. About half-way through the cities is the confluence of the Minnesota River, which differs considerably in quality, with the Mississippi River. To permit observation of the effect on the river of the upstream 13 miles of storm and combined sewer discharge, a monitor had to be located upstream from the river junction. The Minnesota River joins the Mississippi River in a section of rather quiet flow, and there is no dam, waterfall or rapids to aid in mixing. The two rivers appear to flow side by side in a common channel for some distance. To permit observation of the effect of the Minnesota River on the Mississippi River, a monitor was needed somewhat downstream from a point where adequate mixing of the two waters has occurred. Fortunately, there are only a few sewer outfalls in the section of river where this mixing takes place so this monitor location will constitute a good measure of entering condition, upstream from a substantial part of St. Paul's sewer outfalls. The next general location needed is downstream from the remaining St. Paul outlets but upstream of the Minneapolis-Saint Paul Sanitary District Treatment Plant outfall.

The upstream monitor was sited at the Minneapolis Water Treatment Plant which is located just north of the Minneapolis city limits in the suburb of Fridley. A location in the raw water intake pumping station there was easily the best site available. The total annual water diversion is over 28 billion gallons, averaging about 77 MGD or 121 cfs. The river geometry at the pumping station is such that this diversion should provide a good representative sampling of the river.

To insure, as much as possible, that representative samples of river water are provided to the river monitor, the river was cross-sectioned and sampled extensively at each of the other general locations. The contours of the river channel were roughly determined by soundings. Some measurements of current were made but were probably not extremely reliable since they were made with the current meter suspended from a boat which was not always absolutely stationary. Samples were taken at two or three depths at several stations across each cross-section and also at any feasible pump-mounting site. Dissolved oxygen, conductivity and temperature were measured immediately, and samples were also run through the Technicon Autoanalyzer in the Sanitary District laboratory. The automatic analyzer determined concentrations of chloride ion, ammonia-nitrogen, total Kjeldahl nitrogen, phosphate and urea. In each case the data indicated that the proposed sampling sites would provide representative samples.

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Specifications were prepared for the Minneapolis-Saint Paul Sanitary District by Pioneer Service and Engineering Company to provide water quality instrumentation stations. Five river quality monitoring stations were acquired in 1968 under contract from Fairchild Camera and Instrument Corporation of Syosset, New York. Four were mounted in two-wheel trailers, the type used for temporary construction offices. The fifth was provided for permanent installation in the pumping station at the Minneapolis Water Treatment Plant. The units measure pH, conductivity, oxidation-reduction potential, temperature, chlorides and dissolved oxygen. Fairchild Camera and Instrument Corporation has since disposed of its Environmental Systems Operation which is now Automated Environmental Systems, Inc. of Woodbury, New York.

The trailers measure 8 feet by 22 feet and are insulated and equipped with sinks, plumbing, electric heating, ventilating, fluorescent lighting systems, cabinets and a work counter. One sink is provided with a small water reservoir and a pump as a clean water source. The other sink is connected to the sample plumbing and provides a water sample tap at the work counter. The trailers have one door and no windows in an attempt to make them as vandal-proof as possible. The water analyzer unit itself, Figure 41, is quite compact so a smaller trailer could have been used. However, the dollar savings in getting a smaller trailer would have been minimal and it was felt that a larger size would increase their later utility for expanded sampling and analysis work.

The analyzer has local readout meters for each parameter measured and two electrical signal outputs, one 0 to 5 volt range for telemetry and one 0-50 mv. range for local recording. The monitors were bought without local recorders since a computer-based telemetry system was available. Since then, two multipoint strip chart recorders have been acquired; one provides a local recording station at the Minneapolis Water Treatment Plant because of their interest, and the other provides data recording backup in case of telemetry or

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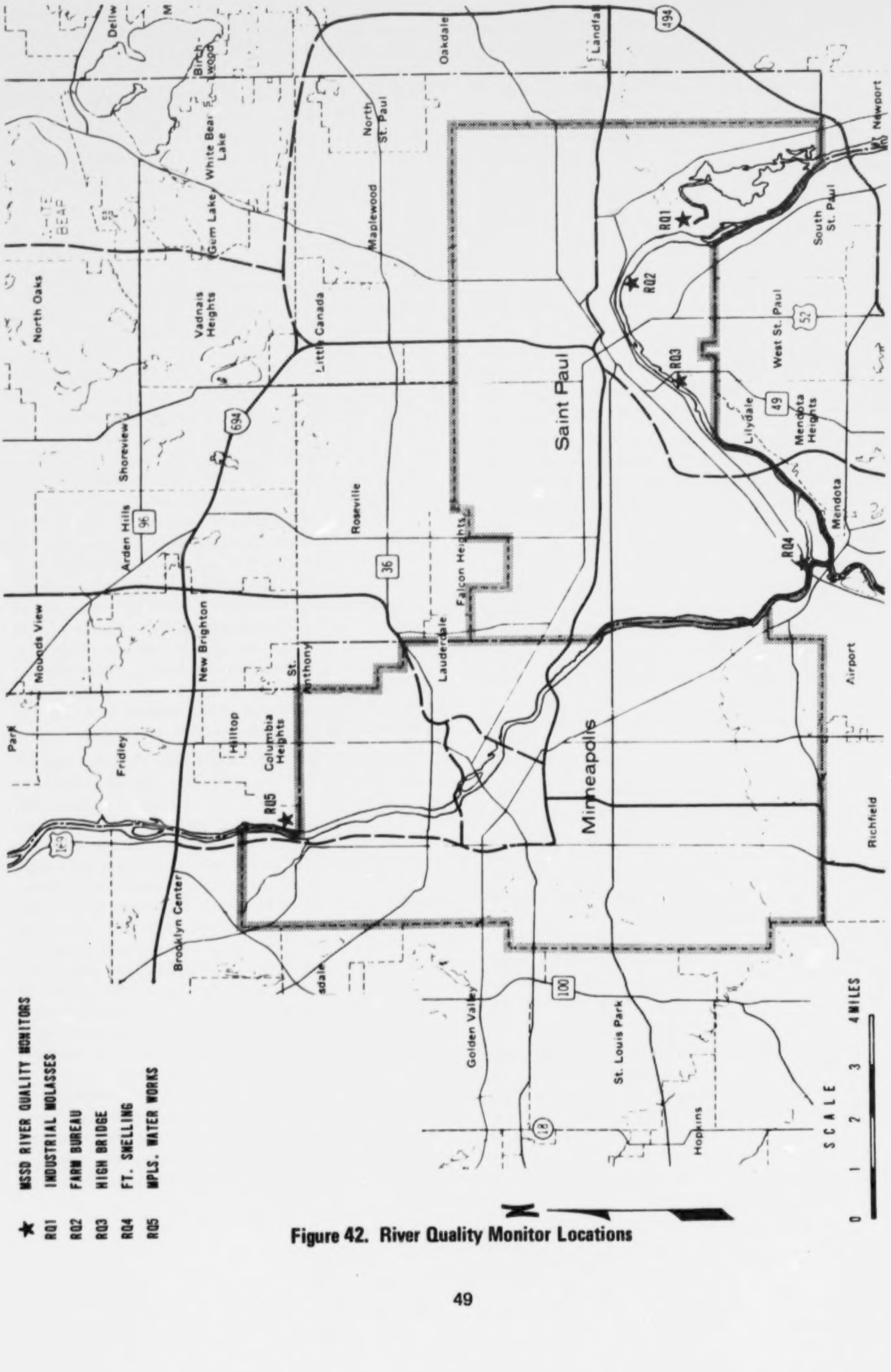
★ MSSD RIVER QUALITY MONITORS
RQ1 INDUSTRIAL MOLASSES
RQ2 FARM BUREAU
RQ3 HIGH BRIDGE
RQ4 FT. SNELLING
RQ5 MPLS. WATER WORKS
N
SCALE
0 1 2 3 4 MILES
RQ1
RQ2
RQ3
RQ4
RQ5
Saint Paul
Minneapolis
North Oaks
Vadnais Heights
Gem Lake
White Bear Lake
Birchwood
Dellw
Shoreview
Arden Hills
Mounds View
New Brighton
Little Canada
Maplewood
North St. Paul
Oakdale
Landfall
Roseville
Falcon Heights
Lauderdale
St. Anthony
Hilltop
Columbia Heights
Fridley
Park
Brooklyn Center
Golden Valley
St. Louis Park
Hopkins
Richfield
Airport
Mendota
Mendota Heights
Lilydale
West St. Paul
South St. Paul
Newport
694
494
96
36
49
52
100
18
169

Figure 42. River Quality Monitor Locations

Because of the inplant work load, the other four installations were made by a local plumbing contractor. Monitor RQ 2 was installed at a fertilizer terminal with the pump mounted from a concrete cell dolphin used for mooring barges at their unloading dock. Because of a flood wall between the trailer and the river, the pipe and power cable were run on the river bottom through an outlet culvert leading into a storm water pumping station discharge wet well and up to the trailer. The pipe above water was again heated, insulated and physically protected by a rigid pipe where exposed. The effluent pipe from the trailer discharges to a storm drain nearby.

Monitor RQ 3 was installed at a cooling water intake pumping station serving Northern States Power Company's High Bridge Power Plant. The trailer was parked next to the pump building and the pump suspended into the wet well channel behind a traveling water screen. The pipe was protected outside the building in the same manner as at the other monitors.

The monitor upstream from the Minnesota River mouth, RQ 4, is located on City property, right-of-way from a since-demolished highway bridge. Because of the narrow width of the river and the barge traffic, the Corps of Engineers would not permit the installation of a pile cluster, even a small distance from the river's edge. Therefore, the pump was mounted on the end of a private marina boat slip. Because of the low elevation of the trailer site and the questionable pump location, no effort was made to heat, insulate or protect the pipe other than by direct burial.

The pump serving river monitor RQ 5 is mounted behind a traveling water screen in a pumping forebay at the Water Treatment Plant. The analyzer was installed in an old meter repair shop now being used only for storage.

The primary operating difficulty has been the need to replace pumps periodically. The pumps run continuously and are subject to wear from silt and sand which is often encountered in the water. The average life expectancy appears to be about four to six months. The pumps are repaired as they are replaced, but the repairs are fairly expensive. Repairs that have been made are replacement of motor and replacement of worn rotor and stator. A few centrifugal pumps were purchased and used, but proved even less reliable, so now only the positive displacement pumps are repaired.

On two occasions, freezing of water in the pipe has caused problems. After a pump failure at RQ 4, new pipes and power cable were run over the snow and ice and the frozen pipe left until spring. We had no freezing problems with unprotected pipes so long as the water flow was continuous. On another occasion, a power outage allowed ice to block a pipe.

RQ 4 had to be moved in October, 1968 when flooding on the Minnesota River submerged the trailer site. Three trailers, RQ 1, RQ 3 and RQ 4 had to be moved in the spring of 1969 during the near record flood on the Mississippi River. In each of these instances the pumps and piping remained in the river and only the trailers were moved. This permitted speedy reinstallation after water levels receded.

Maintenance of the analyzer itself has been limited to cleaning and calibration of sensors. Electronically the equipment has been very reliable. During the winter months when water temperatures are near freezing, maintenance visits for cleaning of sensors and calibration checking at intervals of two weeks were adequate. Very little biological growth in the sample cups and on the sensors occurs and, probably because of the ice cover and absence of river traffic, much less silt accumulates in the sample chamber. During the summer months, however, maintenance visits twice weekly were the rule, primarily to accomplish cleaning of the sensors and the sample cups and drawers. With the exception of the chloride parameter, it has been fairly easy to keep the equipment in calibration, as long as the sensor are kept clean. The chloride sensor is installed in a baffled cup because the probe is velocity sensitive. The baffled cup quite easily becomes fouled by biological growths and by accumulations of sediment. This condition is usually followed by abnormally high chloride ion readings. The chloride sensor is also the most difficult to calibrate probably because of its long thermal time constant and its velocity sensitivity. It does work, however, as evidenced by the increase in chloride concentrations observed when spring thaws flush the heavy amounts of ice melting salt into the river. Figure 45 is an example of this phenomenon.

Maintenance and calibration since the intial start-up of the monitors has been performed almost exclusively by part-time and full-time temporary student employees. Initial calibrations were performed by the project's engineering staff with the assistance of the manufacturers local service group. The project's engineers then trained the student employees. Major calibrations utilizing full-range standards are not believed to be frequently necessary. The usual procedure is to measure the ambient status and make whatever small adjustments necessary. Samples are taken and titrated for DO and chloride ion in the trailer. A portable pH meter and a portable conductivity meter are laboratory calibrated and used as secondary calibration standards. Temperature standard is a measurement by an ordinary laboratory thermometer. Oxidation-reduction potential is always calibrated using standard solutions prepared in the laboratory and carried to the trailer. When major calibrations are performed, the only additions necessary are: zero DO solution since the river is usually near saturation, high

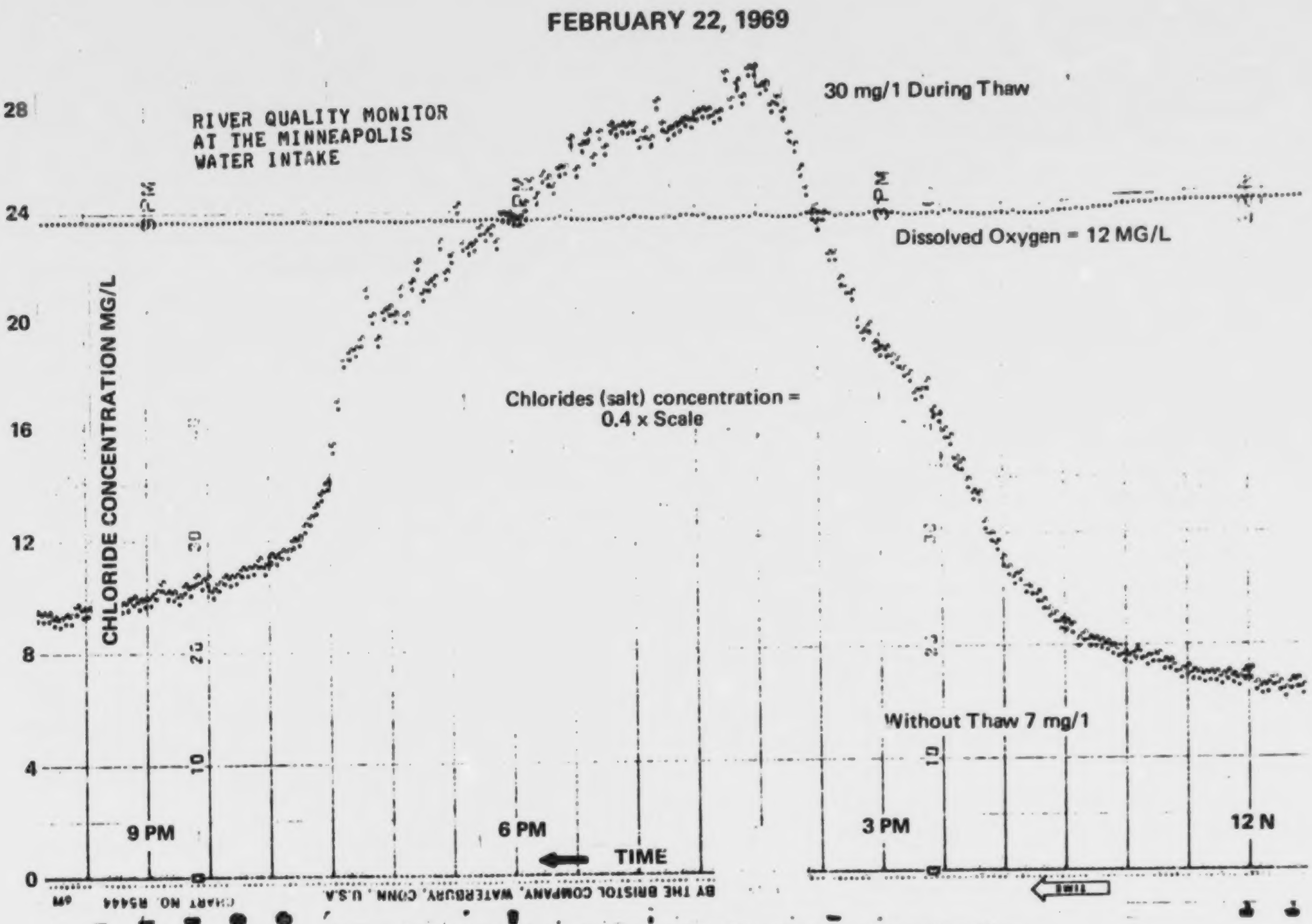

Figure 45. Chloride Data from River Monitor on a Thawing Day

and low chloride standards, two or three pH buffer solutions, two or three conductivity standards and ice.

Some of the parameters were acquired with dual range readout to increase accuracy of transmission and readout. These are DO, temperature and conductivity. The ranges available are illustrated in Table 10 along with the normal full range of each parameter observed.

Table 10
RIVER QUALITY MONITOR PARAMETERS

Parameter	Instrument Range	Approximate Extreme Values Maximum	Approximate Extreme Values Minimum
Dissolved Oxygen	0-24 mg/1 0-12 mg/1	14.2 mg/1	5.8 mg/1
Temperature	30 - 80° F. 50 - 100° F.	83.0° F.	32.0° F.
Conductivity	0 - 600 umhos 0 - 1200 umhos	620 umho	220 umho
Chloride	0 - 48 mg/1	20.5 mg/1	4.2 mg/1
pH	4 - 10	8.7	7.4
Oxidation-Reduction Potential	–600 - +600 mv	585	310

Findings and Conclusions

River monitoring data acquired during and immediately after rainfall events of sufficient intensity to have caused appreciable combined sewer overflow to the river were closely scrutinized. The effort was made in an attempt to evaluate the significance of the effect of pollution slugs originating from combined and storm sewer outlets in Minneapolis and Saint Paul on the Mississippi River. It was thought that depletion in dissolved oxygen concentration might occur because of the BOD entering the river in storm and combined sewer discharge. Because of the low chloride concentration in the river water (5-10 mg/1), it was thought that an increase in chloride concentration might be observed.

During and after most rainfall events, no changes were observed in any of the parameters measured at any of the river monitoring stations. There were a few instances when some reductions in DO were noted following rain, but they were very slight in magnitude. Diurnal variations in concentration of DO were often in evidence so this, plus the possible effect of cloud cover variability, complicates the situation and increases the uncertainty that any slight change should be attributed to pollution from combined or storm sewer discharges.

Extremely low river flow conditions did not occur during the summer of 1969 despite the fact that rainfall for the Minneapolis-Saint Paul area was relatively low. Table 11 shows monthly maximum, mean and minimum Mississippi River flows at St. Paul for April through November of 1969. The minimum recorded discharge at the Mississippi River at St. Paul is 632 cfs. At more critically low river flows, the effects of combined and storm sewer flows would be more pronounced.

Table 11

MISSISSIPPI RIVER DISCHARGE
APRIL – NOVEMBER, 1969
UNOFFICIAL RECORDS FOR ST. PAUL

	Mississippi River Discharge at Saint Paul, cfs		
	Minimum Day	**Mean**	**Maximum Day**
April	32,400	88,500	148,600
May	20,600	39,000	59,000
June	10,500	14,900	20,200
July	9,600	14,200	18,500
August	3,400	5,900	9,800
September	2,700	3,400	4,500
October	3,400	5,000	5,700
November	3,700	5,300	7,100

In 1969, data from the river monitoring system indicates that the dissolved oxygen resources of the Mississippi River in Minneapolis and St. Paul were not adversely affected by storm and combined sewer discharges.

Bacteriological effects were likely more pronounced, but the only data available are from periodic grab samples that are completely uncoordinated with rainfall events. Anderson (4) attempted to analyze river coliform count and BOD statistically for recent years in an attempt to gage the effect of improved regulator surveillance and modifications. The limited number of observations makes it difficult to base any significant conclusions upon these data.

VIII. COMPUTER ANALYSIS OF STORM RUNOFF AND MATHEMATICAL MODEL OF THE REGULATOR-INTERCEPTOR SYSTEM

In November, 1967, the Minneapolis-Saint Paul Sanitary District entered into an agreement with the University of Minnesota St. Anthony Falls Hydraulic Laboratory to have prepared a mathematical model of the existing interceptor sewer system. Work toward development of this program has been reported in four status reports (5, 6, 7, 8).

Verification of the program, modification for use on the PDP-9 computer at the Sanitary District, and the rainfall loss-rate analysis not complete at the time of preparation of the earlier reports have all since been completed. Verification of the program was accomplished using real data obtained from the outplant data logging system during the summer of 1969.

The final report on this project entitlted "Mathematical Model of Urban Storm Runoff and the Interceptor Sewer System of the Minneapolis-Saint Paul Sanitary District" has been submitted to the Minneapolis-Saint Paul Sanitary District and is included as Part II of this report.

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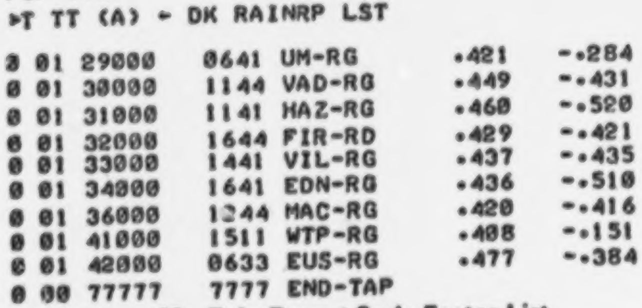
IX. OPERATION OF THE SYSTEM

Data Acquisition Programs

Data acquisition or scanning is under control of a group of programs collectively named "RTIME", short for REAL TIME. The RTIME routine is called up by issuing a one line command from the I/O teletype. The operator then initializes the computer internal clock by typing in the hour of the day, the minute of the hour, and the day of the year. The computer internal clock then maintains the time, which is entered on all reports and stored with all data. RTIME will initiate scanning, either under control of the computer internal clock, or by receiving manually initiated signals from the interface control panel. As each address is scanned, an electrical analog signal from the telemetry is digitized and read into the computer which referring to the appropriate list of scaling factors (Figure 46), stores it in a file, and prepares a written report. At this time there are five outplant scanning routines used in RTIME. Normal scanning employs four:

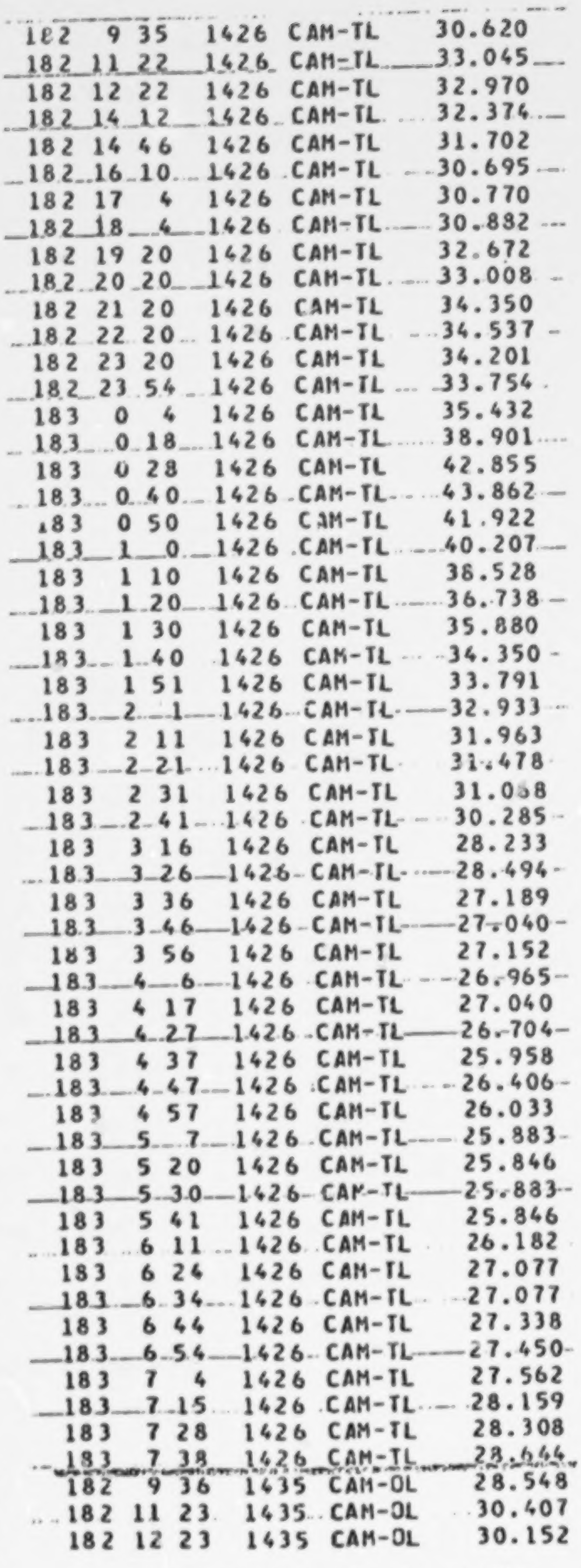
1. RIVMON which scans the river quality monitors.
2. REGCTL which scans the regulator control and monitoring stations.
3. INCPTR which scans the interceptor monitoring stations.
4. RAINRP which scans the rain gages.



```
PIP V7B
>T TT (A) ← DK RAINRP LST

0 01 29000   0641 UM-RG         .421     -.284
0 01 30000   1144 VAD-RG        .449     -.431
0 01 31000   1141 HAZ-RG        .460     -.520
0 01 32000   1644 FIR-RD        .429     -.421
0 01 33000   1441 VIL-RG        .437     -.435
0 01 34000   1641 EDN-RG        .436     -.510
0 01 36000   1244 MAC-RG        .420     -.416
0 01 41000   1511 WTP-RG        .408     -.151
0 01 42000   0633 EUS-RG        .477     -.384
0 00 77777   7777 END-TAP
```

Figure 46. Rain Report Scale Factor List

The fifth routine, ALARM, can be used to scan extra addresses at almost all stations which are called "alarm points." When any of these scanning routines operate, the data is added to a file stored on the magnetic disk. These files are usually allowed to accumulate for 24 hours from 8:00 A.M. to 8:00 A.M., closed, and given a distinctive name be which they can later be accessed. Figure 47 is an example of one of these files that was printed on the line printer. The names used are made up of 9 characters. For example RISR70 140 is a name for a file of river quality monitoring data (RI) occurring in a sorted but unpacked format (SR) for the period in the year 1970 (70) approximately 24 hours in length beginning at 8:00 A.M. on the 140th day of the year (140). Should this file later be packed, a process by which its magnetic storage requirements are reduced, it would be renamed RISP70 140.



```
182  9 35  1426 CAM-TL    30.620
182 11 22  1426 CAM-TL    33.045
182 12 22  1426 CAM-TL    32.970
182 14 12  1426 CAM-TL    32.374
182 14 46  1426 CAM-TL    31.702
182 16 10  1426 CAM-TL    30.695
182 17  4  1426 CAM-TL    30.770
182 18  4  1426 CAM-TL    30.882
182 19 20  1426 CAM-TL    32.672
182 20 20  1426 CAM-TL    33.008
182 21 20  1426 CAM-TL    34.350
182 22 20  1426 CAM-TL    34.537
182 23 20  1426 CAM-TL    34.201
182 23 54  1426 CAM-TL    33.754
183  0  4  1426 CAM-TL    35.432
183  0 18  1426 CAM-TL    38.901
183  0 28  1426 CAM-TL    42.855
183  0 40  1426 CAM-TL    43.862
183  0 50  1426 CAM-TL    41.922
183  1  0  1426 CAM-TL    40.207
183  1 10  1426 CAM-TL    38.528
183  1 20  1426 CAM-TL    36.738
183  1 30  1426 CAM-TL    35.880
183  1 40  1426 CAM-TL    34.350
183  1 51  1426 CAM-TL    33.791
183  2  1  1426 CAM-TL    32.933
183  2 11  1426 CAM-TL    31.963
183  2 21  1426 CAM-TL    31.478
183  2 31  1426 CAM-TL    31.068
183  2 41  1426 CAM-TL    30.285
183  3 16  1426 CAM-TL    28.233
183  3 26  1426 CAM-TL    28.494
183  3 36  1426 CAM-TL    27.189
183  3 46  1426 CAM-TL    27.040
183  3 56  1426 CAM-TL    27.152
183  4  6  1426 CAM-TL    26.965
183  4 17  1426 CAM-TL    27.040
183  4 27  1426 CAM-TL    26.704
183  4 37  1426 CAM-TL    25.958
183  4 47  1426 CAM-TL    26.406
183  4 57  1426 CAM-TL    26.033
183  5  7  1426 CAM-TL    25.883
183  5 20  1426 CAM-TL    25.846
183  5 30  1426 CAM-TL    25.883
183  5 41  1426 CAM-TL    25.846
183  6 11  1426 CAM-TL    26.182
183  6 24  1426 CAM-TL    27.077
183  6 34  1426 CAM-TL    27.077
183  6 44  1426 CAM-TL    27.338
183  6 54  1426 CAM-TL    27.450
183  7  4  1426 CAM-TL    27.562
183  7 15  1426 CAM-TL    28.159
183  7 28  1426 CAM-TL    28.308
183  7 38  1426 CAM-TL    28.644
182  9 36  1435 CAM-OL    28.548
182 11 23  1435 CAM-OL    30.407
182 12 23  1435 CAM-OL    30.152
```

Figure 47. Data File as Stored on the Disk

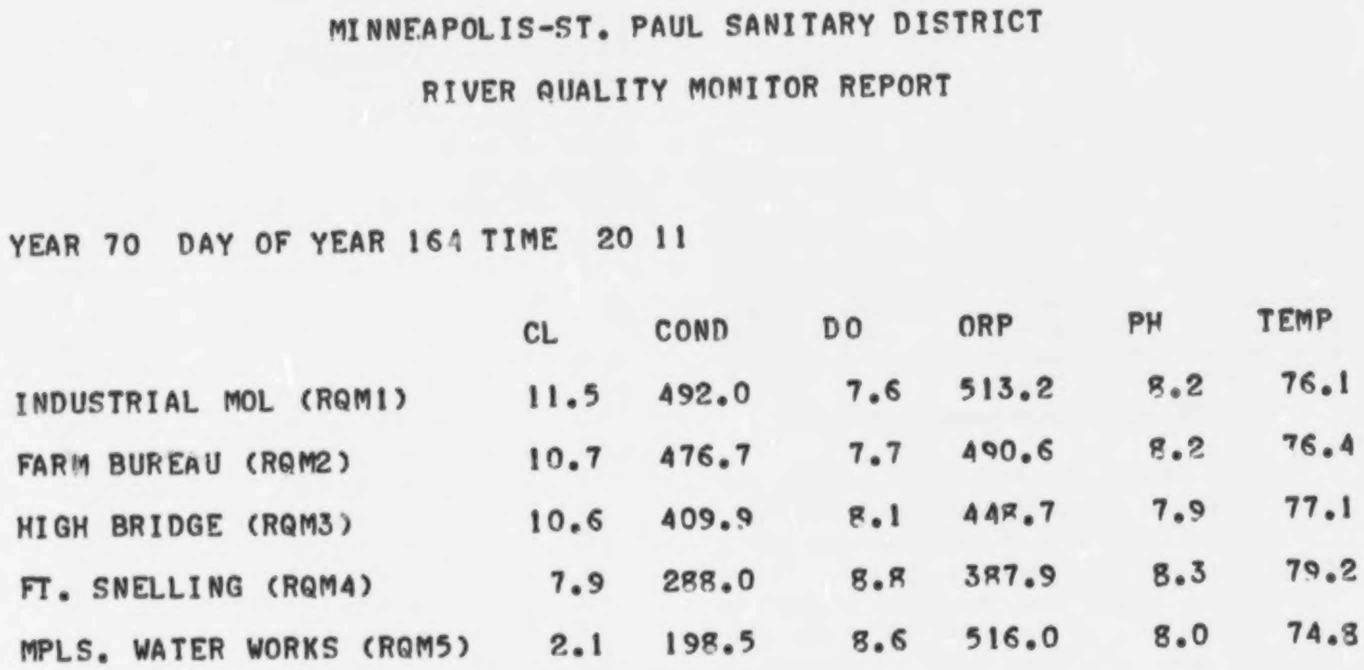
Preceding page blank

The River Quality Monitor Report available immediately after scanning is shown in Figure 48.

The Regulator Control Report is shown in Figure 49. The station names used are familiar to the operating personnel and tables are available to assist a less familiar person in interpreting the data. Camden Park through Oak Street are regulators in Minneapolis, and Rice & Rondo through Eustis-West are regulators in Saint Paul. Their locations are referenced in Figure 26. Trunk level (TL) is the depth of flow in the trunk sewer just upstream of the regulator. Outlet level (OL) is the depth of flow in the dry weather outlet pipe which carries diverted flow from the regulator gate controlling flow into the outlet pipe expressed as per cent open. Storm gate (SG) is the inflation pressure inside the Fabridam. At Camden Park regulator, where there is no Fabridam, SG represents per cent open for a bypass gate.

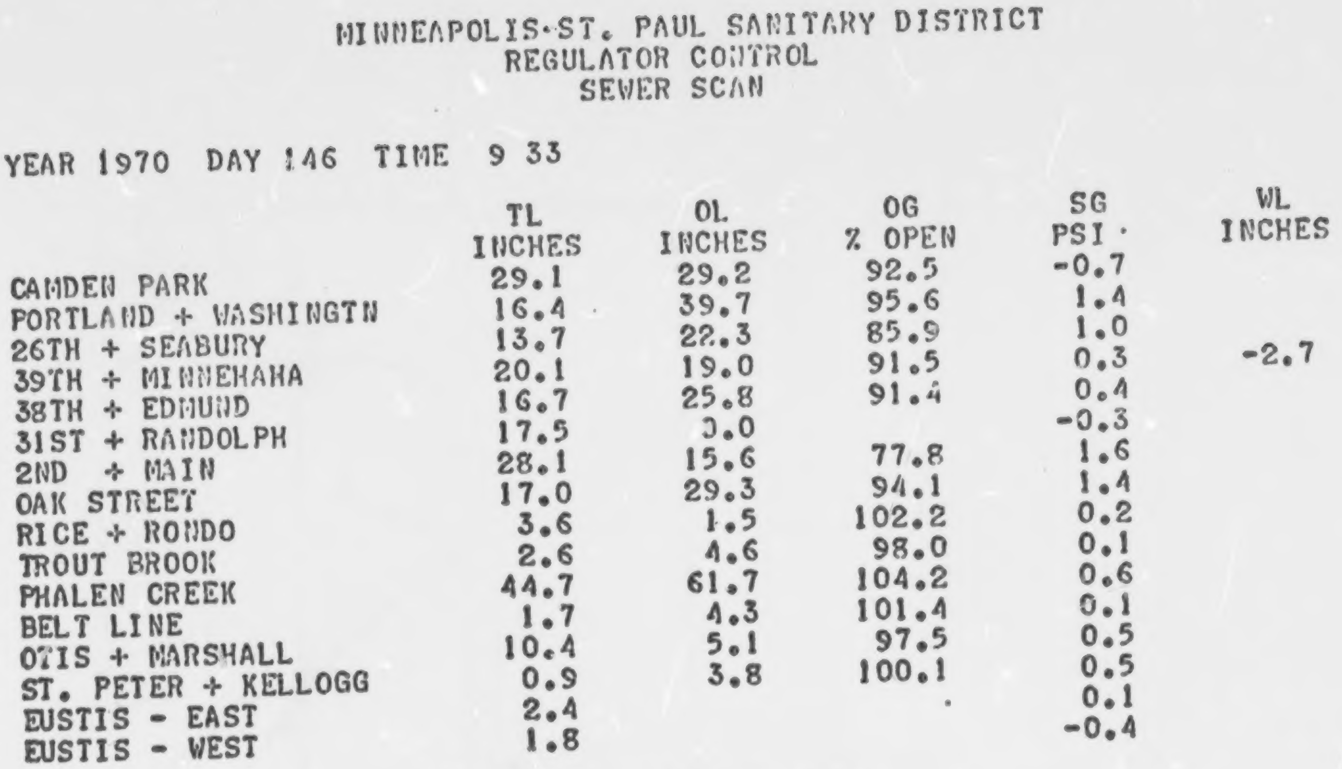
The Interceptor Report is shown in Figure 50. The names used refer to the locations of the monitoring stations, which are referenced on Figure 51. Level is depth of flow in the interceptor in inches. The section sizes and shapes are referenced in Table 12. Bypass gates at the ends of the three Minneapolis interceptors are remote controlled and their positions monitored. The other two gate positions on the report refer to gates at the entrances to the two parallel Venturi meters on the Northwest interceptor. Usually only one meter is in use, but during rain periods the second gate can be remotely opened and two meters used. This is accomplished automatically when flow through the other Venturi meter exceeds a set point value. The flow rates in MGD and levels at Bypass and Headhouse are actually inplant data received from old metering and telemetry equipment in use before the Regulator Demonstration Program.

The Rain Report is shown in Figure 52. The rain gage names used represent their locations and are referenced on Figure 25. In addition to the data from



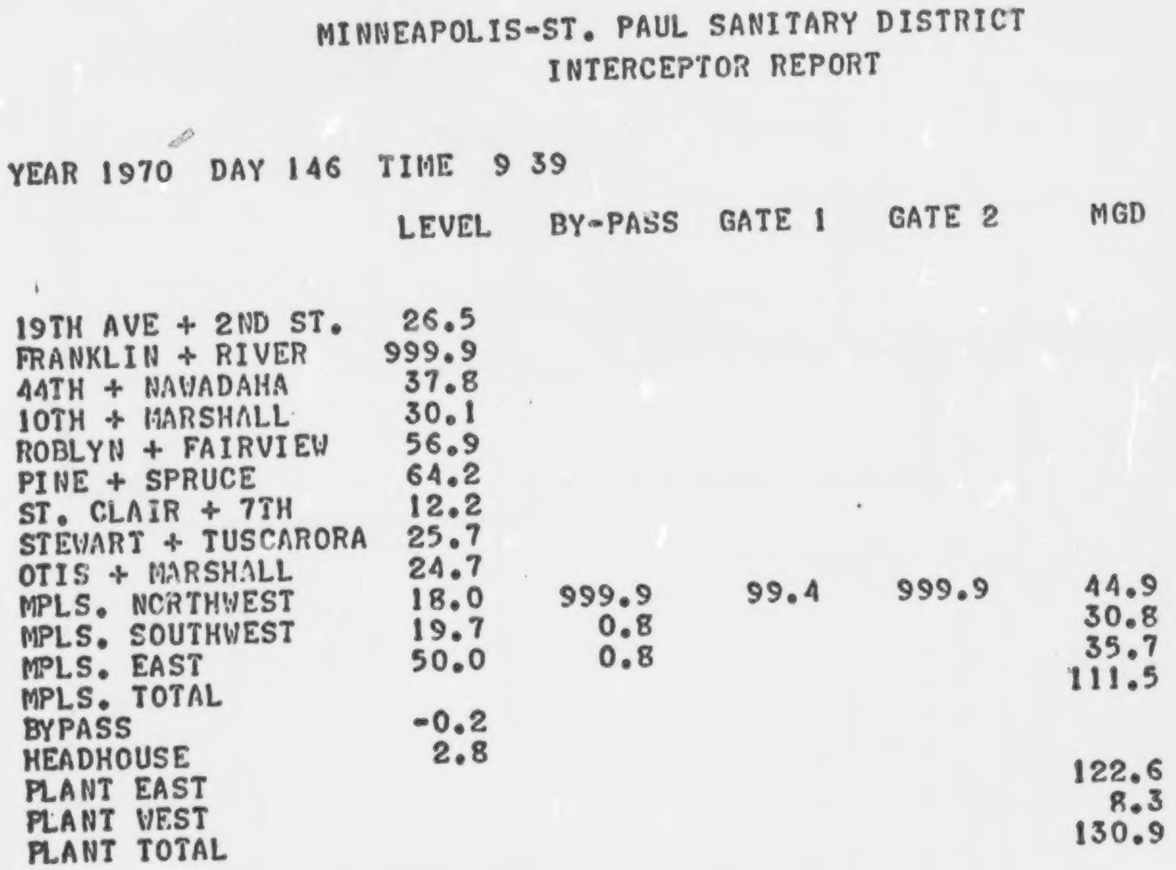
```
                      MINNEAPOLIS-ST. PAUL SANITARY DISTRICT
                           RIVER QUALITY MONITOR REPORT


YEAR 70  DAY OF YEAR 164 TIME  20 11

                              CL      COND      DO     ORP       PH     TEMP

INDUSTRIAL MOL (RQM1)        11.5    492.0      7.6   513.2      8.2    76.1

FARM BUREAU (RQM2)           10.7    476.7      7.7   490.6      8.2    76.4

HIGH BRIDGE (RQM3)           10.6    409.9      8.1   448.7      7.9    77.1

FT. SNELLING (RQM4)           7.9    288.0      8.8   387.9      8.3    79.2

MPLS. WATER WORKS (RQM5)      2.1    198.5      8.6   516.0      8.0    74.8
```

Figure 48. River Quality Monitor Report



```
                     MINNEAPOLIS-ST. PAUL SANITARY DISTRICT
                                REGULATOR CONTROL
                                   SEWER SCAN

YEAR 1970  DAY 146  TIME  9 33
                              TL         OL         OG          SG        WL
                            INCHES     INCHES     % OPEN       PSI      INCHES
CAMDEN PARK                  29.1       29.2       92.5        -0.7
PORTLAND + WASHINGTN         16.4       39.7       95.6         1.4
26TH + SEABURY               13.7       22.3       85.9         1.0      -2.7
39TH + MINNEHAHA             20.1       19.0       91.5         0.3
38TH + EDMUND                16.7       25.8       91.4         0.4
31ST + RANDOLPH              17.5        0.0                   -0.3
2ND  + MAIN                  28.1       15.6       77.8         1.6
OAK STREET                   17.0       29.3       94.1         1.4
RICE + RONDO                  3.6        1.5      102.2         0.2
TROUT BROOK                   2.6        4.6       98.0         0.1
PHALEN CREEK                 44.7       61.7      104.2         0.6
BELT LINE                     1.7        4.3      101.4         0.1
OTIS + MARSHALL              10.4        5.1       97.5         0.5
ST. PETER + KELLOGG           0.9        3.8      100.1         0.5
EUSTIS - EAST                 2.4                               0.1
EUSTIS - WEST                 1.8                              -0.4
```

Figure 49. Regulator Control Report



```
                MINNEAPOLIS-ST. PAUL SANITARY DISTRICT
                          INTERCEPTOR REPORT


YEAR 1970  DAY 146  TIME  9 39
                         LEVEL   BY-PASS   GATE 1   GATE 2     MGD


19TH AVE + 2ND ST.        26.5
FRANKLIN + RIVER         999.9
44TH + NAWADAHA           37.8
10TH + MARSHALL           30.1
ROBLYN + FAIRVIEW         56.9
PINE + SPRUCE             64.2
ST. CLAIR + 7TH           12.2
STEWART + TUSCARORA       25.7
OTIS + MARSHALL           24.7
MPLS. NORTHWEST           18.0    999.9     99.4    999.9      44.9
MPLS. SOUTHWEST           19.7      0.8                        30.8
MPLS. EAST                50.0      0.8                        35.7
MPLS. TOTAL                                                   111.5
BYPASS                    -0.2
HEADHOUSE                  2.8
PLANT EAST                                                    122.6
PLANT WEST                                                      8.3
PLANT TOTAL                                                   130.9
```

Figure 50. Interceptor Report

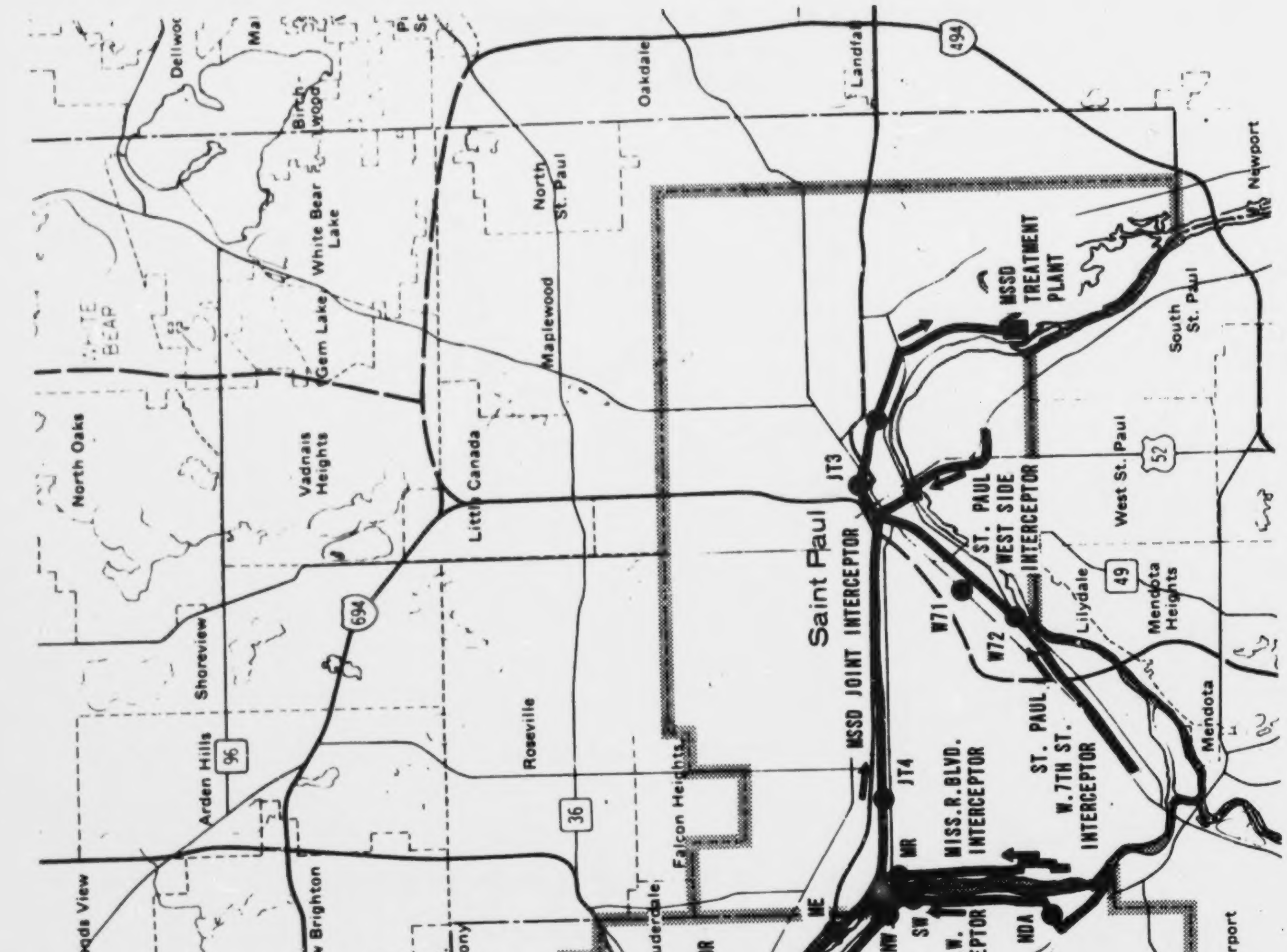
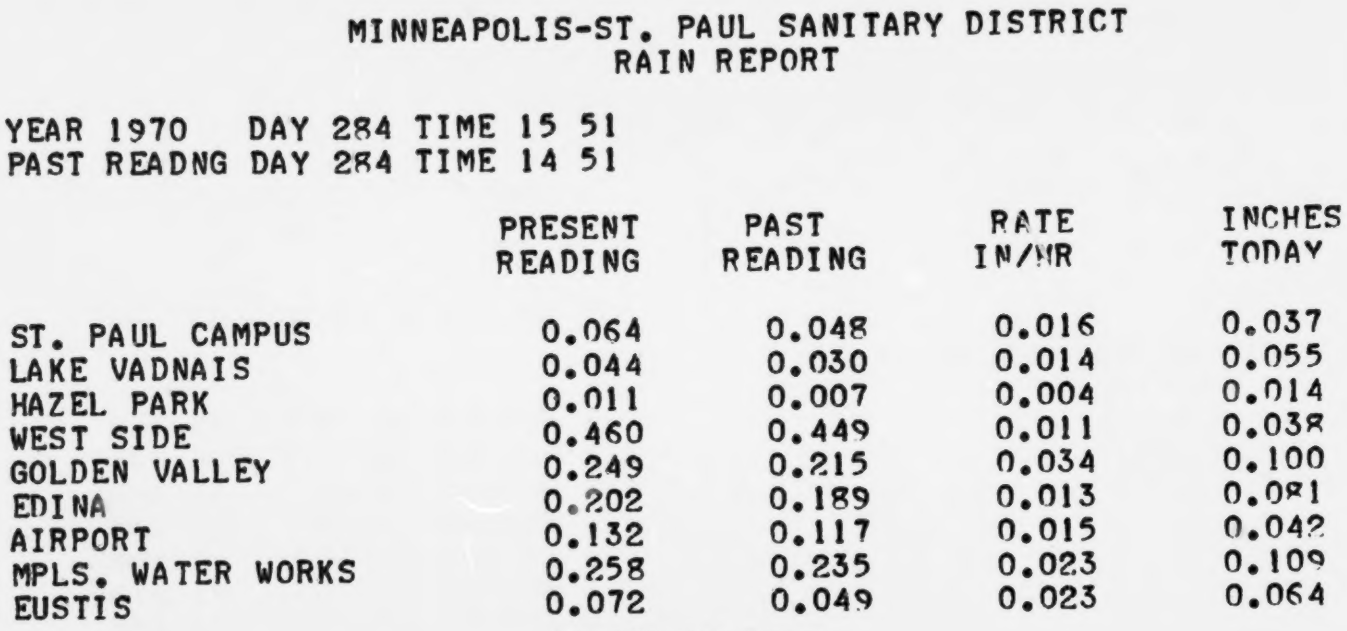

● INTERCEPTOR MONITORING STATIONS
M2 10TH AVE. AND 2ND ST.
FR FRANKLIN AND RIVER RD.
NDA 44TH AND NAWADAHA BLVD.
ME2 10TH AND MARSHALL
JT4 ROBLYN AND FAIRVIEW
JT3 PINE AND SPRUCE
W71 ST. CLAIR AND W. 7TH
W72 STEWART AND TUSCORORA
MR OTIS AND MARSHALL
NW MPLS. NORTHWEST
SW MPLS. SOUTHWEST
ME MPLS. EAST
SCALE
0 1 2 3 4 MILES
N
MPLS.N.W. INTERCEPTOR
MPLS.E. INTERCEPTOR
MPLS.S.W. INTERCEPTOR
MISS.R.BLVD. INTERCEPTOR
ST. PAUL W.7TH ST. INTERCEPTOR
ST. PAUL WEST SIDE INTERCEPTOR
MSSD JOINT INTERCEPTOR
MSSD TREATMENT PLANT
M2
ME2
FR
NW
SW
ME
MR
NDA
JT4
JT3
W71
W72
Minneapolis
Saint Paul
Hopkins
St. Louis Park
Golden Valley
Richfield
Airport
Brooklyn Center
Fridley
Columbia Heights
Hilltop
St. Anthony
New Brighton
Lauderdale
Falcon Heights
Roseville
Arden Hills
Mounds View
Shoreview
North Oaks
Vadnais Heights
Little Canada
Gem Lake
White Bear Lake
Birchwood
Maplewood
North St. Paul
Oakdale
Landfall
Dellwood
West St. Paul
South St. Paul
Lilydale
Mendota Heights
Mendota
Newport
169
100
18
96
694
36
494
49
52

Figure 51. Interceptor Monitoring Stations



```
                  MINNEAPOLIS-ST. PAUL SANITARY DISTRICT
                              RAIN REPORT

YEAR 1970   DAY 284 TIME 15 51
PAST READNG DAY 284 TIME 14 51
                          PRESENT     PAST        RATE       INCHES
                          READING     READING     IN/HR      TODAY

ST. PAUL CAMPUS            0.064       0.048      0.016      0.037
LAKE VADNAIS               0.044       0.030      0.014      0.055
HAZEL PARK                 0.011       0.007      0.004      0.014
WEST SIDE                  0.460       0.449      0.011      0.038
GOLDEN VALLEY              0.249       0.215      0.034      0.100
EDINA                      0.202       0.189      0.013      0.081
AIRPORT                    0.132       0.117      0.015      0.042
MPLS. WATER WORKS          0.258       0.235      0.023      0.109
EUSTIS                     0.072       0.049      0.023      0.064
```

Figure 52. Rain Report

Table 12

INTERCEPTOR LEVEL MEASUREMENT LOCATIONS AND SIZES

Location	Size
MINNEAPOLIS:	4'-6"
19th and 2nd Streets	4'-0" x 4'-6"
Nawadaha	3'-6" x 6'-0"
S. W. Meter	6'-0" x 6'-0"
Franklin	9'-0" x 9'-0"
N. W. Meter	10'-3" x 10'-3"
East Meter	6'-0" x 6'-0"
Tenth and Marshall	7'-0" x 7'-4"
SAINT PAUL:	
Mississippi River Boulevard	3'-9" x 5'-10"
Tuscarora	2'-6" x 6'-0"
Fairview	11'-9½"
Pine and Spruce	13'-1"
St. Clair	3'-9" x 5'-10"

the scan run, this report also contains the data from the last prior scan, the rainfall rate during the intervening period in inches per hour, and the total accumulation since the file day began. The readings are inches of water equivalent to the weight in the collector bucket.

A routine called SCNFRQ for SCAN FREQUENCY is a part of RTIME and can be used to vary scan rates. The operator calls the routine by depressing the appropriate switch on the operator's console. Any interval between scans can be indicated in seconds; the various routines can and often are scanned at different rates. Figure 53 shows the teletype commands that would be used to change scan frequencies from hourly to rates commonly used during rainfall.

Gates and Fabridams can be contolled remotely both under program control and manually through the interface cabinet. Any address can be manually accessed and the analog voltage read so monitoring and control remain possible even without the use of the computer. The program by which control functions are normally exercised is called GATCON for GATE CONTROL. It can be manually initiated or called by the computer internal clock. As presently constituted, the program will access any gate or Fabridam whose address is written in a list called SETGAT LST (Figure 54), check the position of the gate or inflation of the Fabridam, and brings the position or inflation pressure into agreement with a set point that it also reads from the list if the actual value differs from the set point by prescribed limits. A GATE control report is shown in Figure 55. The remark "INOPERABLE" is printed if the gate position reading does not reach the set point value ± 2% within a period of time specified on SETGAT LST.

Modes of Operation

During dry weather the system is used for data acquisition, data reduction and processing, and for programming. Normally, scans run at hourly intervals. The gate control program, GATCON, runs every three hours to maintain all outlet gates 100% open and all Fabridams inflated. While most of the Fabridams are not effective in or required for diversion of dry weather flow, they are better kept inflated because of the rather lengthy time that would be required to inflate 15 fully deflated dams—about 75 minutes—and because they need be deflated only during very intense rainstorms that do not occur frequently.

Each day at about 8:00 A.M. the data files, RIVMON DLY, REGCTL DLY, INCPTR DLY, AND RAINRP DLY, are renamed with a unique name

```
MONITOR V4B

SE RTIME

 ENTER- HR MN DAY

 08 45 146

ENTER ID AND RATE-(X XXXXX)


ID PROGRAM

 2 RIVER
 3 REGTR
 4 INCPT
 5 RAIN
 6 ALARM
 7 SETGT
 8 SLUDGE
 9 EXIT

ENTER ID AND RATE-(X XXXXX)

2 01800

OLD RATE WAS   3600
ENTER ID AND RATE-(X XXXXX)

3 00900

OLD RATE WAS   3600
ENTER ID AND RATE-(X XXXXX)

4 00600

OLD RATE WAS   3600
ENTER ID AND RATE-(X XXXXX)

5 00300

OLD RATE WAS   3600
ENTER ID AND RATE-(X XXXXX)

9
```

Figure 53. Use of SCNFRQ Routine to Control Scanning Frequency

```
PIP V7B

>T TT (A) - DK SETGAT LST


 1 000225 M2-SG     70 180
 2 000227 M2-OG     98 060
 3 000245 PW-SG     65 180
 4 000247 PW-OG    100 060
 6 000305 OAK-SG    70 180
 7 000307 OAK-OG    96 010
 8 000425 SPK-SG    70 180
 9 000427 SPK-OG   100 060
10 000505 RR-SG     70 240
11 000507 RR-OG    100 060
12 000545 TB-SG     70 240
13 000547 TB-OG     85 030
18 000745 KD-SG     70 180
19 000747 KD-OG     98 060
20 001045 BL-SG    070 240
21 001047 BL-OG     92 060
22 001025 PC-SG     65 180
23 001027 PC-OG     95 010
24 001226 NWI-G1    95 060
31 001307 M39-OG    90 060
32 001345 SEA-SG    68 180
33 001347 SEA-OG    96 030
35 001427 CAM-OG    95 060
36 001547 RAN-SG    70 180
38 001745 E38-SG    70 180
39 001747 E38-OG    92 015
77 007777
```

Figure 54. Fabridam and Gate Control List

```
                    MINNEAPOLIS-ST. PAUL SANITARY DISTRICT
                              GATE CONTROL REPORT

YEAR 1970  DAY 146  TIME  9 45


GATE NO ADDRESS MNEMONIC % OPEN  WAS DESIRED  REMARKS
   1     0225    M2-SG        69  67      70
   2     0227    M2-OG        97  87      98
   3     0245    PW-SG        70  70      65  INOPERABLE
   4     0247    PW-OG        99  96     100
   6     0305    OAK-SG       71  72      70
   7     0307    OAK-OG       94  95      96
   8     0425    SPK-SG       68  86      70
   9     0427    SPK-OG       98  98     100
  10     0505    RR-SG        72  93      70
  11     0507    RR-OG       101 101     100
  12     0545    TB-SG        70  93      70
  13     0547    TB-OG        84  81      85
  18     0745    KD-SG        72  86      70
  19     0747    KD-OG        98  98      98
  20     1045    BL-SG        77  91      70
  21     1047    BL-OG        90  90      92
  22     1025    PC-SG        67  80      65
  23     1027    PC-OG        95  95      95
  24     1226    NWI-G1       94  94      95
  31     1307    M39-OG       89  87      90
  32     1345    SEA-SG       68  79      68
  33     1347    SEA-OG       93  93      96  INOPERABLE
  35     1427    CAM-OG       95  96      95
  36     1547    RAN-SG       76  99      70
  38     1745    E38-SG       71  87      70
  39     1747    E38-OG       89  90      92
```

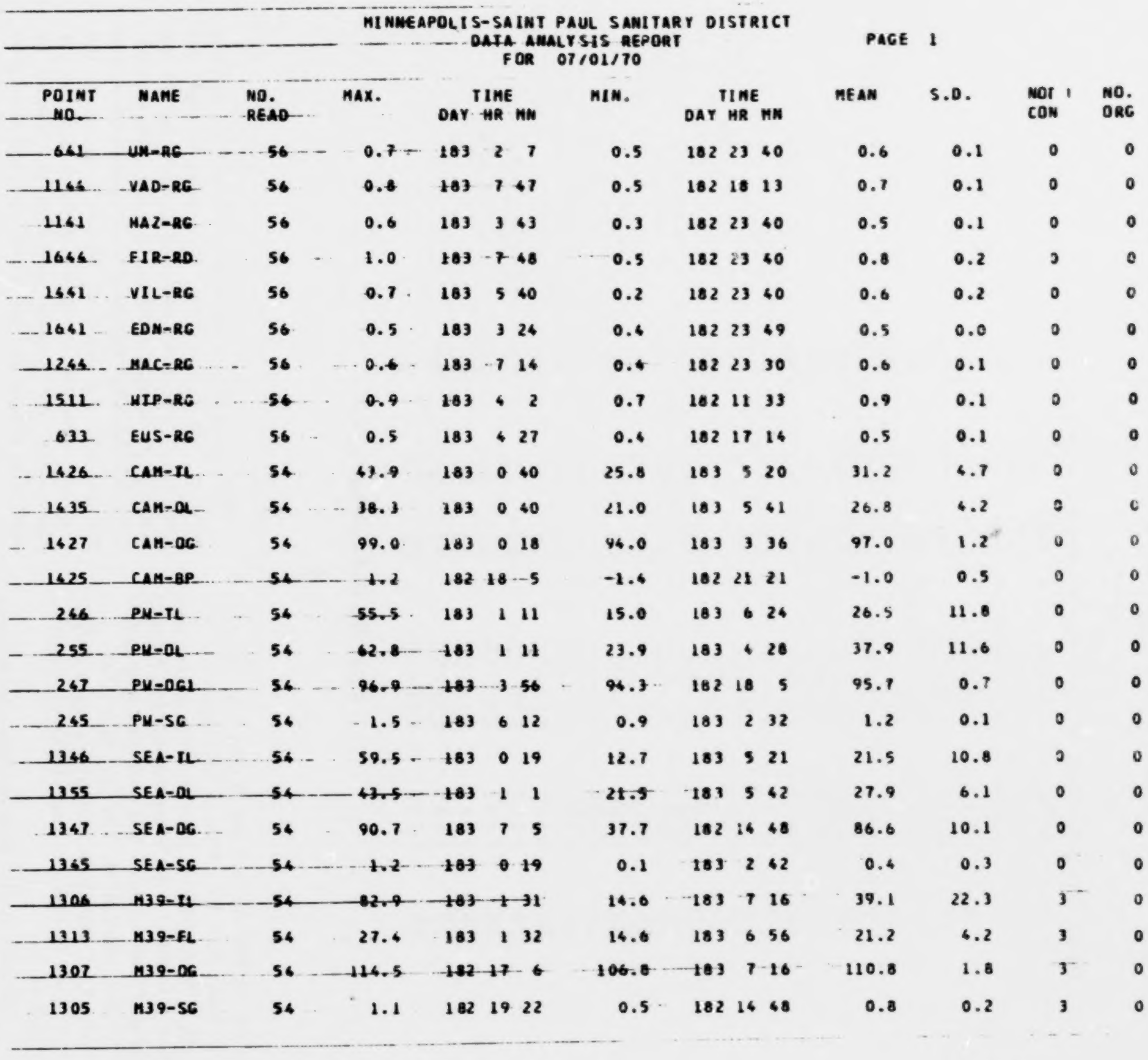
Figure 55. Gate Control Report

describing the file's content and its date. The next scan run will begin new daily files. A hard paper copy of each file is then obtained from the line printer. The data files are usually quickly scanned to look for data indicating problems—either real problems or problems in monitoring equipment. The scaling routines will record a 9's field, 9999.9, in place of any figure outside a normal range to make it easier to spot unusual or abnormal data.

If the telemetry system does not successfully access a specific address, it is noted by a failure of the address to "confirm." Confirmation of an address occurs when the outplant station returns to the base station a pair of tones corresponding to those sent by the base telemetry as part of the unique address. The failure of an address to confirm is indicated by a 7's field, 7777.7, so it is easily recognized, and this failure does not generate misleading data. The paper copies are bound serially and retained for later reference.

The data is also reduced using a DATA ANALYSIS program named DANALS. This program reads the entire data file and, after calculations, prints the address, the number of times the address was scanned, the maximum observed value of the parameter at that address and the time at which it occurred, the minimum value and the time at which it occurred, the mean value, the standard deviation, the number of times that address did not confirm and the number of values falling outside a set range. Figure 56 is an example of a DANALS Report. These reports are also bound serially and retained.

Renamed, closed data files remain on the magnetic disk surface, but must be removed so that adequate room is available on the disk for new data files and programs. Magnetic disk is too expensive to be used for data storage and the high speed capabilities of the disk are not required for data storage.



```
                                   MINNEAPOLIS-SAINT PAUL SANITARY DISTRICT
                                          DATA ANALYSIS REPORT                  PAGE  1
                                            FOR  07/01/70

 POINT   NAME      NO.     MAX.       TIME        MIN.       TIME        MEAN      S.D.     NOT    NO.
  NO.             READ             DAY HR MN              DAY HR MN                         CON    ORG

  641   UM-RG       56     0.7     183  2  7      0.5     182 23 40      0.6       0.1       0      0
  1144  VAD-RG      56     0.8     183  7 47      0.5     182 18 13      0.7       0.1       0      0
  1141  HAZ-RG      56     0.6     183  3 43      0.3     182 23 40      0.5       0.1       0      0
  1644  FIR-RD      56     1.0     183  7 48      0.5     182 23 40      0.8       0.2       0      0
  1441  VIL-RG      56     0.7     183  5 40      0.2     182 23 40      0.6       0.2       0      0
  1641  EDN-RG      56     0.5     183  3 24      0.4     182 23 49      0.5       0.0       0      0
  1244  MAC-RG      56     0.6     183  7 14      0.4     182 23 30      0.6       0.1       0      0
  1511  WIP-RG      56     0.9     183  4  2      0.7     182 11 33      0.9       0.1       0      0
  633   EUS-RG      56     0.5     183  4 27      0.4     182 17 14      0.5       0.1       0      0
  1426  CAM-TL      54    43.9     183  0 40     25.8     183  5 20     31.2       4.7       0      0
  1435  CAM-OL      54    38.3     183  0 40     21.0     183  5 41     26.8       4.2       0      0
  1427  CAM-OG      54    99.0     183  0 18     94.0     183  3 36     97.0       1.2       0      0
  1425  CAM-BP      54     1.2     182 18 -5     -1.4     182 21 21     -1.0       0.5       0      0
  246   PW-TL       54    55.5     183  1 11     15.0     183  6 24     26.5      11.8       0      0
  255   PW-OL       54    62.8     183  1 11     23.9     183  4 28     37.9      11.6       0      0
  247   PW-OG1      54    96.9     183  3 56     94.3     182 18  5     95.7       0.7       0      0
  245   PW-SG       54     1.5     183  6 12      0.9     183  2 32      1.2       0.1       0      0
  1346  SEA-TL      54    59.5     183  0 19     12.7     183  5 21     21.5      10.8       0      0
  1355  SEA-OL      54    43.5     183  1  1     21.5     183  5 42     27.9       6.1       0      0
  1347  SEA-OG      54    90.7     183  7  5     37.7     182 14 48     86.6      10.1       0      0
  1345  SEA-SG      54     1.2     183  0 19      0.1     183  2 42      0.4       0.3       0      0
  1306  M39-TL      54    82.9     183  1 31     14.6     183  7 16     39.1      22.3       3      0
  1313  M39-FL      54    27.4     183  1 32     14.6     183  6 56     21.2       4.2       3      0
  1307  M39-OG      56   114.5     182 17  6    106.8     183  7 16    110.8       1.8       3      0
  1305  M39-SG      54     1.1     182 19 22      0.5     182 14 48      0.8       0.2       3      0
```

Figure 56. Data Analysis Report

If it is desired to retain a file, it can be stored on magnetic tape or on paper tape. It can be stored in its initial format or it can be packed. A packing routine has been prepared which reduces the "space" requirement for data storage by about 60%. The magnetic tape used is referred to as DECTAPE, and the computer is equipped with two DECTAPE drives. A dectape library of 128 reels is in use for program backup storage as well as data storage. Each reel contains 150,000 eighteen bit words on 260 feet of 3/4 inch magnetic tape. Punch paper tape in use is the 1 inch fan fold type. A paper tape library contains programs backup and diagnostic and test programs.

Almost all data collected in the first year of operation was stored on magnetic tape. It is impractical to consider continuing this practice so, after inspection, verification that a paper copy exists, and completion of the data analysis program, some of the older files have been deleted from magnetic storage. All files containing data acquired during and immediately after rainfalls have been retained, however, so further data analysis could easily be accomplished.

Another data processing program that has been developed is a data plotting routine named GRAPHP. This program will plot data on the line printer from all or any part of any particular file. The time axis (horizontal) plotting interval and the data axis (vertical) full scale value are selected by the operator, so the plotting routine is quite flexible. Usually only the rain-day data was plotted since it was carefully scrutinized as part of the project evaluation. Figure 57, Figure 58, and Figure 59 are examples of plotted data from the rainfall occurring on July 1 and 2, 1970.

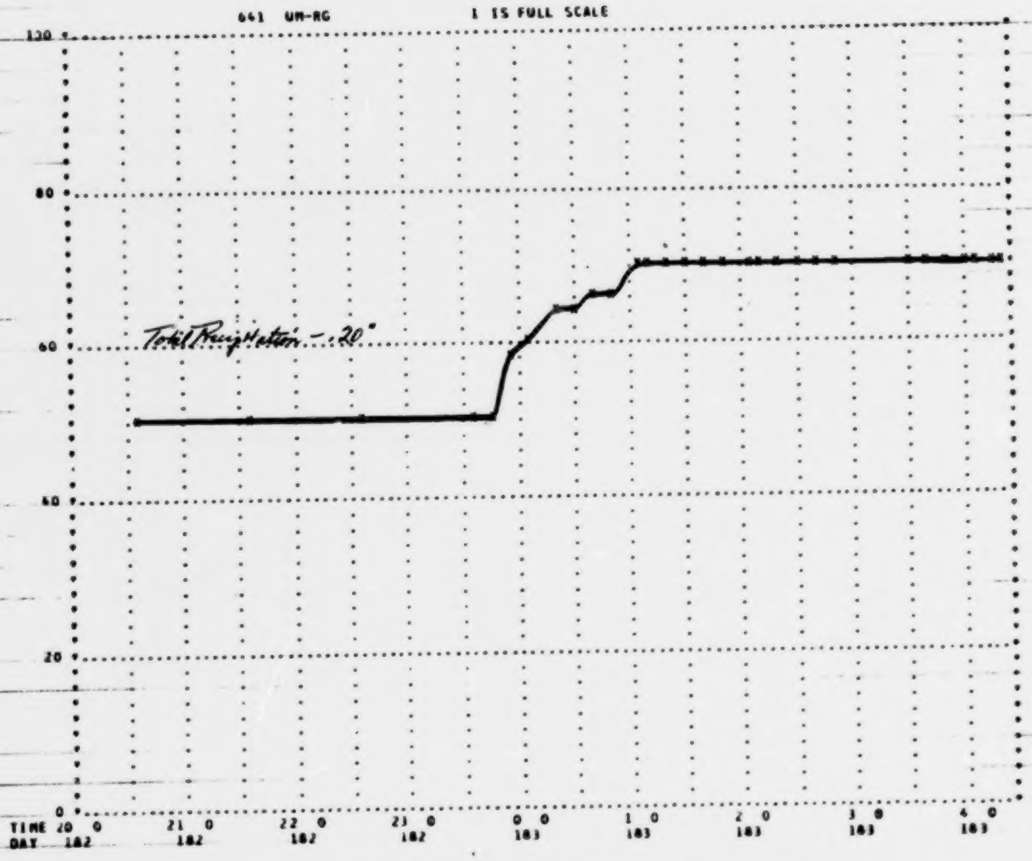


Figure 57. Machine Plotted Rain Gage Data for July 1-2, 1970

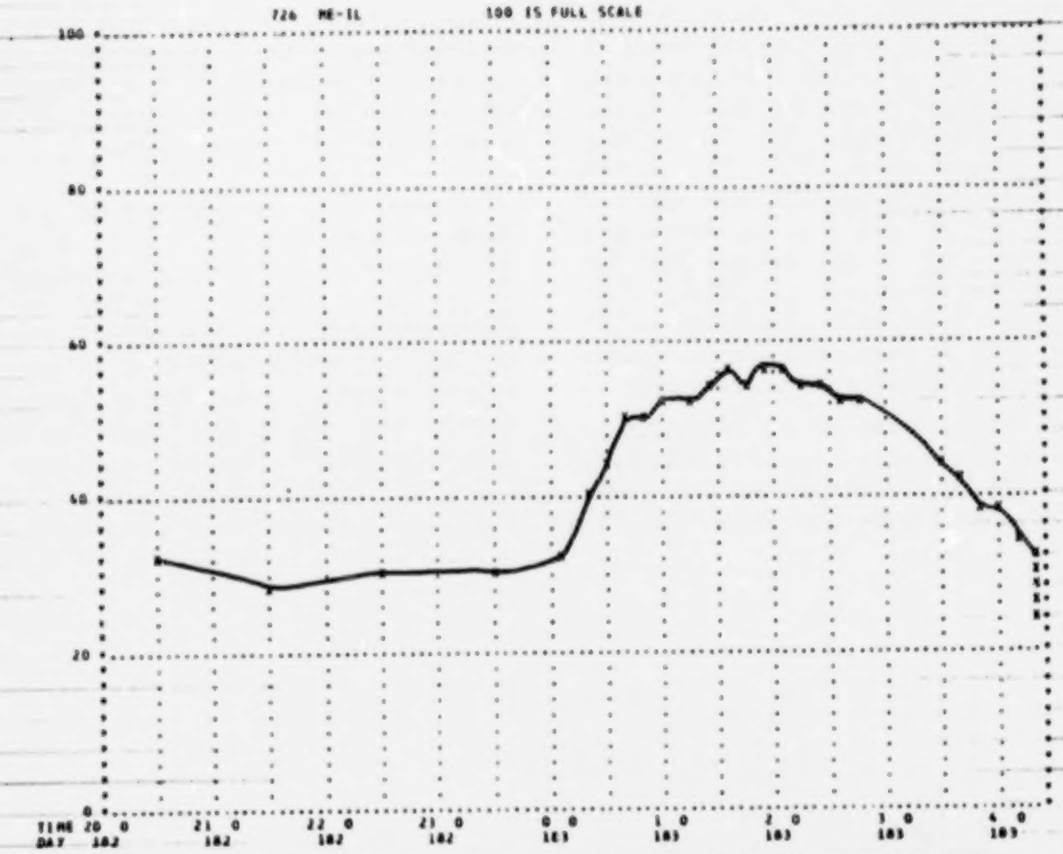


Figure 58. Machine Plotted Interceptor Sewer Flow Depth Data for July 1-2, 1970

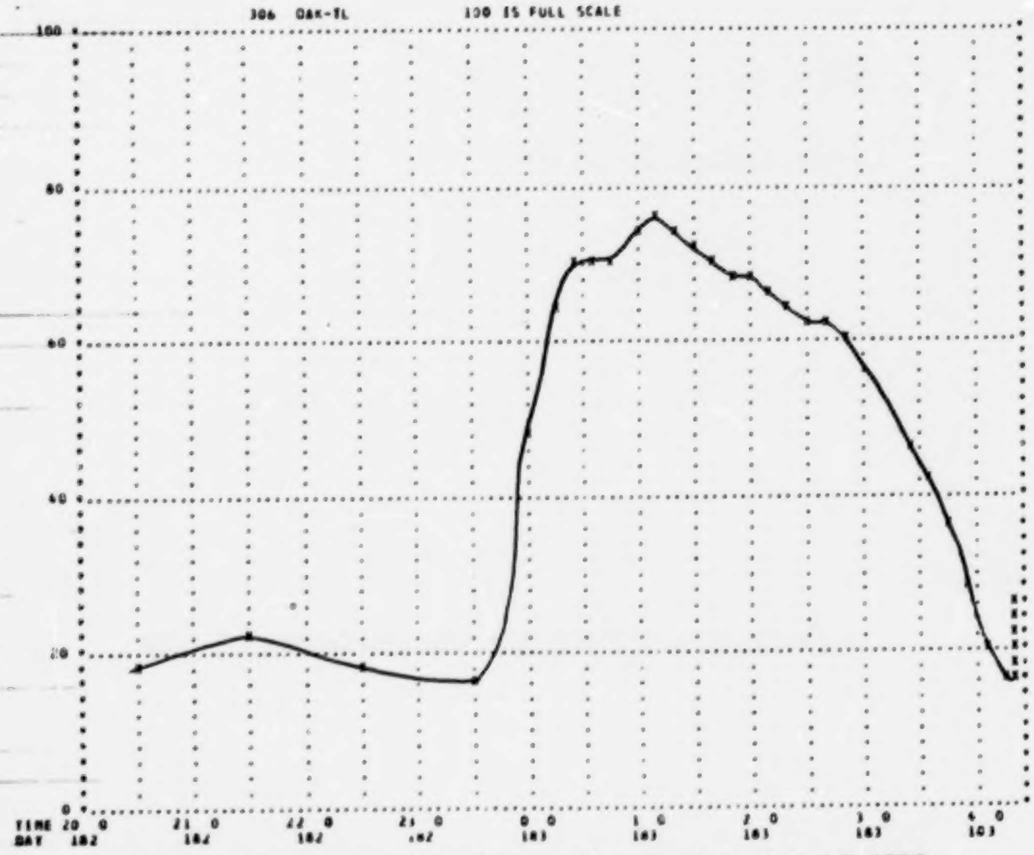


Figure 59. Machine Plotted Trunk Sewer Flow Depth for July 1-2, 1970

A second plotting program called OGIVE was developed for our system. An ogive is a type of curve used to graphically portray frequency distributions in a cummulative manner. It shows the per cent of time or frequency that a measurement of a certain magnitude or greater occurs. This technique was used to portray utilization of interceptors in studies carried out in 1960 (2). Figure 60 is an ogive prepared from 1960 data and Figure 61is an ogive prepared from 1969 data at the same location in the interceptor.

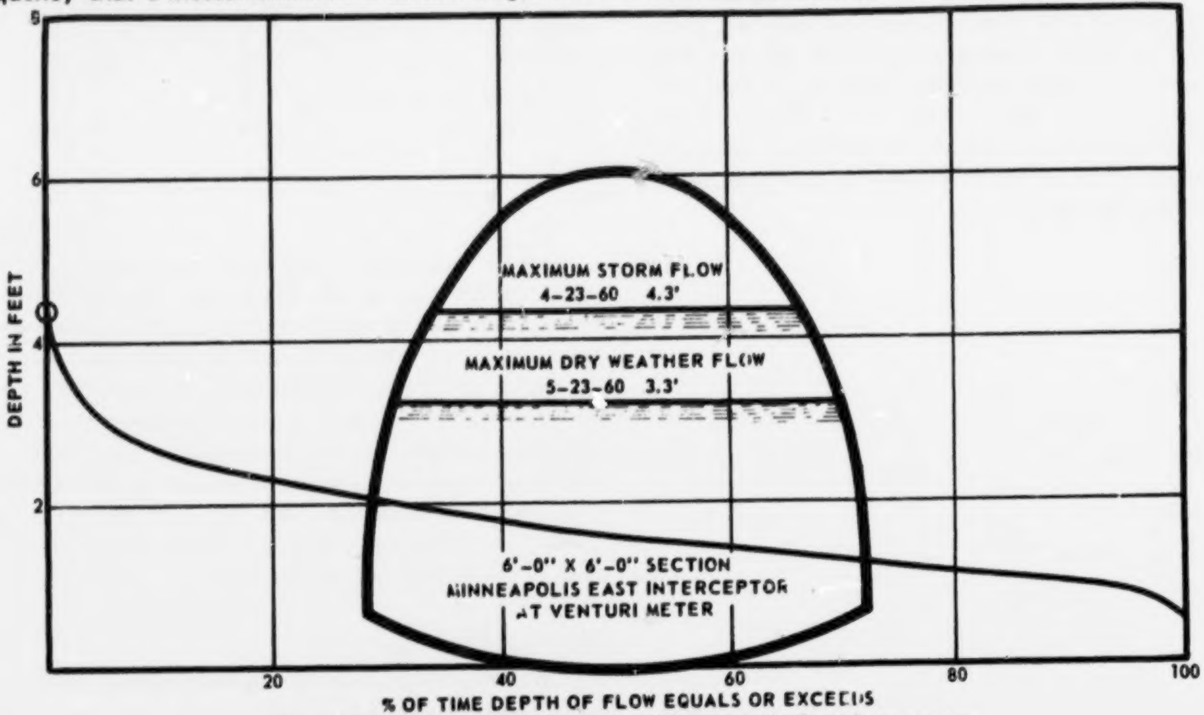


Figure 60. Ogive—1960 Data for Minneapolis East Interceptor

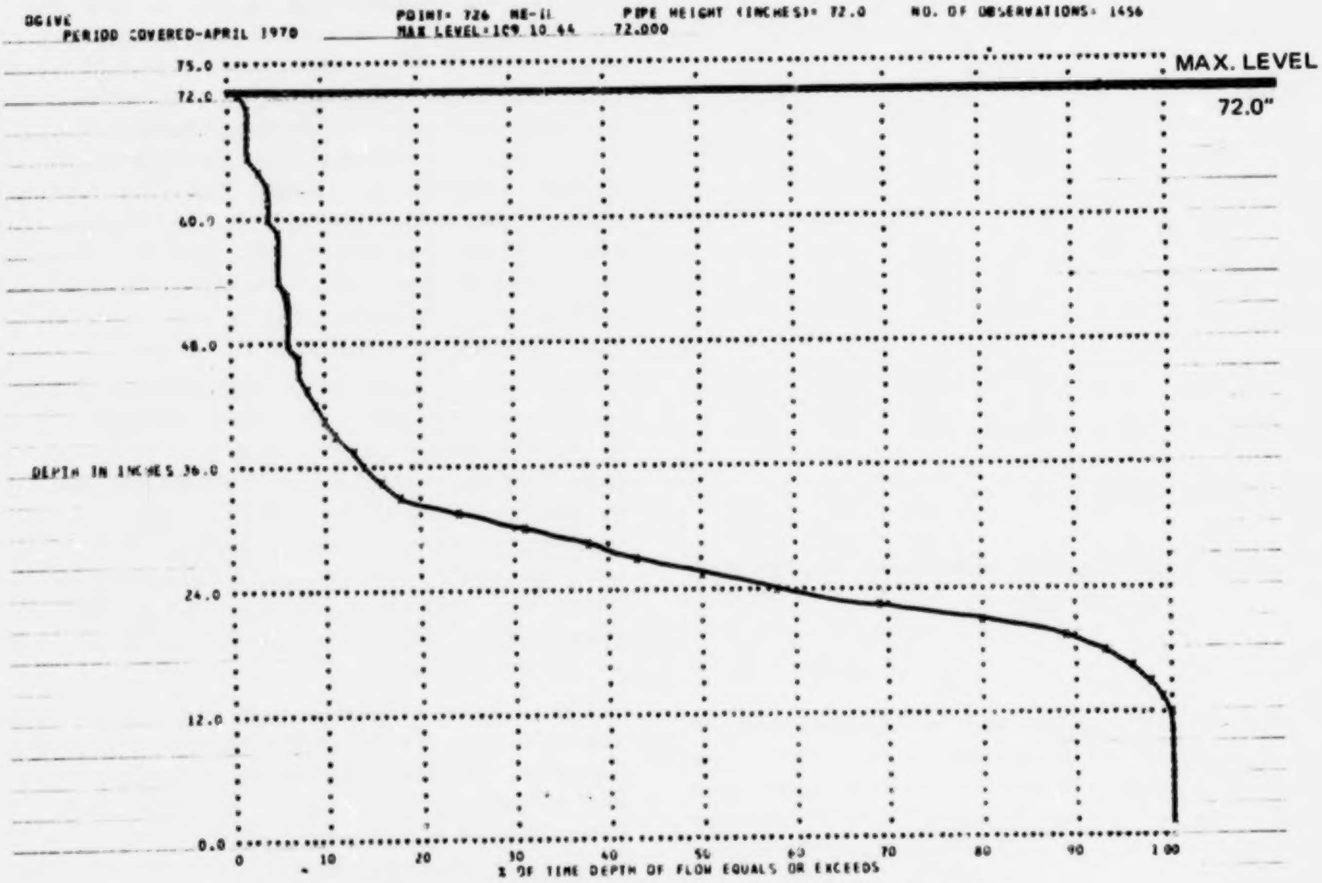


Figure 61. Ogive—1970 Data for Minneapolis East Interceptor

Mounted in the interface cabinets in the computer room and in the Plant Operator's office are eight two-pen miniature strip chart recorders. Data addresses assigned to these pens are recorded on the strip charts moving at one inch per hour. The pens are updated at 8-second intervals, so if all 16 pens are assigned, each address's data value is updated every 128 seconds. The routine which is used to assign addresses to recorder pens is named SEL REC for SELECTION-RECORDER. Figure 62 shows the operator command string at the teletype which is used to assign addresses to the 16 recorder pens.

```
↑C

MONITOR V4B

$E RTIME

 ENTER- HR MN DAY

 08 50 146

 ENTER RECDR AND POINT NO.-(XX XXXX)

01 1511

NEXT

02 1441

NEXT

03 1641

NEXT

04 1244

NEXT

99  (99 Exits Program)
```

Figure 62. Assigning Data Addresses to Recorder Pens Using SELREC

The RTIME program can be operated with or without the reports being concurrently typed out on the logging teletype. When the report is typed, more time is required to scan all points. Table 13 shows the time required for each scan, with and without output to the teletype.

Table 13

SCANNING TIME REQUIREMENTS – MINUTES

	With Teletype Output	Without Teletype Output
RAINRP	1	0.5
INCPTR	2	1.5
RIVMON	2	1.5
REGCTL	6	4.0
TOTAL	11	7.5

Normal operation of the scanning program, RTIME, employs the disk as the file device. The flexibility of the system was demonstrated during the early part of the summer of 1969 when various equipment bugs led to use of the scanning program in various ways. When the disk was unavailable, a modified program was used which wrote the data file on magnetic tape. When the Dectapes were unavailable, a version of the scanning program that used the ASR 33 TTY as the output device enabled the teletype's paper tape punch to record the data in processible form.

Modes of Operation

Operation of the system during rainfall events can be accomplished with or without the use of the mathematical model. Personnel familiar with the system and its operation are usually on duty during periods of rainfall. The mathematical model program incorporates RTIME, and can handle the acquisition of data. The model also produces reports, records data, and makes recommendations for operator action. The operator can then change gate positions either from the teletype keyboard or manually from the operator's panel. The model then checks the changed gate positions with the current data and will show the results of operator action. The model can alert the operator when excessive flow at any point in the interceptor system is expected.

Use of the model as an operator aid during a rainstorm would likely be as follows. The operator has loaded the model program, and it is scanning rain gages. The model is requested to use the rain gage data to calculate a runoff hydrograph anticipated at each regulator, perform a diversion analysis at each regulator, calculate volumes diverted to the interceptor and to the river, and route the flows through the interceptor system, checking for excess flow at each inlet and at other key places.

The operator can choose to have any or all of this data printed on the line printer. Most likely, he would first check the results of the diversion analysis to see if any overflow to the river is predicted. With this information he is alerted as to which trunk sewers will be carrying the largest storm hydrographs and when the storm flow will be arriving. He can then check real data at appropriate times to verify if Fabridam deflation is required to prevent surcharging of the trunk sewer.

The routing portion of the program will print the flow hydrograph at any point in the interceptor system where the predicted flow exceeds the capacity of the pipe. Assume that in this storm, the model warns of excessive flow at the Minneapolis East Interceptor Meter Station. The operator, noting the time at which this will occur, checks a bypass priority table, decides where flow release is preferred, and tests the result of lowering the Fabridam using the model.

After performing the diversion analysis and routing with the changed regulator condition, the model no longer predicts excessive flow, so the operator now deflates the Fabridam.

By this time, the model has accumulated more rainfall data and can update its predictions. The operator can also check real time flow data from the regulators and interceptors.

The system can also be operated manually, without use of the model. The operator has assigned rain gages to the trend recorders and can check rainfall accumulation every two minutes. Depending upon the rain gage results, there will be certain trunk sewers where depth data should be checked. Operating experience from 1969 has indicated which trunk sewers are likely to carry large flow hydrographs. Trunk sewer level data can be assigned to trend recorders so that locations where Fabridam deflation might be required can be watched. By watching trend recorders and data logging reports, the operator can keep abreast of what is happening and control gates and dams to accomplish the best operation within limitations of the interceptor system.

Operation of the system during 1969 was usually less routine. The mathematical model had not been calibrated and was not available for use. The trend recorders were not usable either. Early operation then consisted of insuring that data scans were run frequently and checking rainfall accumulation, trunk sewer level, interceptor level, and Fabridam pressure data as they were logged on the logging teletype.

The only operator actions taken were to deflate dams when the depth of flow in the trunk sewer approached the sewer crown. This was not required very often. During extremely heavy rainfall, flow conditions at many regulators caused rapid increases in Fabridam pressure causing them to deflate through the water column. It is always preferable to relieve air in a controlled manner using the deflation valve, but the storm water hydrograph arrives very suddenly at some regulators after intense thunderstorms. Trunk level data could be obtained every six minutes, but usually only about every ten minutes because rain gage and interceptor scans were also run. Therefore, it was often not possible to note a rapidly rising trunk level and react to it in time to prevent the overpressuring of the Fabridam and its subsequent automatic deflation.

Better operation of Fabridams is now possible, and fewer instances of uncontrolled deflation should occur. Controlled deflation from the base station will be more timely because of the use of the rapidly updated trend recorders. Also, local pressure sensing switches have been installed at several regulators to open the deflation valve and relieve pressure before it has increased to the level of the water column.

This type of "automation" could be expanded somewhat with more local control loops, but at this time it is not necessary. The computer and supervisory control system are also used at several key locations to automatically control gates and Fabridams. The second Venturi meter on the Minneapolis Northwest Interceptors is brought into use when flow through the other meter exceeds a set point, and the Fabridam at the Beltline Regulator in Saint Paul is deflated when the flow depth measured at the head end of the dry weather outlet pipe exceeds a set value. More gates and dams could be automatically controlled in this manner.

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X. SYSTEM EFFECTIVENESS

Data accumulated in operation of the system during rainfall events were analyzed to determine its effectiveness in reducing combined sewer overflow pollution. Effectiveness could be evaluated by several approaches. One used was to enumerate the overflows prevented. Another was the duration of overflow prevented, and a third was the volume of overflow prevented. All three approaches were used.

Three distinct bodies of data were analyzed. A number of rainfall events occurring during the 1969 rainfall season were well described. This data was analyzed over the winter season. Overflow reduction from the 1970 spring thaw runoff was also evaluated. The third group of data was rainfall events occurring during April and May, 1970. Data from 1969 and 1970 rains were combined and seasonal figures were extrapolated.

Rainfall Events Analyzed

The initial operating season used for evaluation of the project was that of 1969. Considerable effort was required to ready the system for operation and acquisition of data, since full-time use of the system was not acquired from the contractor until January, 1969. Scanning and data acquisition programs were ready in time but the winter weather had caused further complications. Heavy snowfall over most of Minnesota resulted in predictions of record or near record flood crests on the Mississippi River in Saint Paul. In 1965 the greatest flood on record had occurred and inundated the Sanitary District plant site; there was a very strong possibility that this would recur. Even flood levels much lower than predicted would have submerged the access road to the plant and also submerged the telephone cable leading to the plant. It was certain then that the flood would interrupt data acquisition for at least two weeks. With project plans already behind schedule, and not wishing to have to wait until 1970 to acquire operating data, the Sanitary District moved the equipment to a temporary location on March 25, 1969. Although the flood had passed and plant operation had restarted on April 28, 1969, the move back to the Sanitary District offices was delayed until August 4, 1969, because of the fear that equipment damage during a move might prevent acquisition of data or confuse the contract negotiations with Badger Meter Manufacturing Company.

The move to the temporary project operating headquarters had apparently caused some equipment problems. These problems and other hardware bugs caused some operating difficulties in the early part of the summer, and some rains occurred for which no data was obtained. The flexibility of the system allowed data acquisition to continue through some hardware problems, which were all finally resolved on July 10, 1969.

Unfortunately, the rainfall occurring during the spring and summer of 1969 was less than normal, so there were fewer opportunities to operate the system and obtain operating data. May through September rainfall was only 58 per cent of normal. August and September were particularly dry months. Precipitation data for the last five years compared with the Weather Bureau Climatological Standard Normals in Table 14 shows that 1969 was the driest year of recent record. Table 15 shows 1969 monthly precipitation data in comparison with the normal for each month. All 1969 precipitation amounts are those measured by the U.S. Weather Bureau's official gage in Minneapolis. Because of problems caused by the flood related move, operation in April was incomplete, so the months of operation were May through November. Only October had higher than normal precipitation.

Because of the importance of acquiring data and the shortage of manpower, extensive analysis of data obtained was delayed until the conclusion of the rainfall season. A review of all data obtained led to the selection of sixteen rainfall events to be studied further and used for the project evaluation. The first of these sixteen rains occurred on April 24 and the last on November 16. During this period, 13.00 inches fell at the Weather Bureau Station and 7.46 inches of this fell during the 16 rainfall events selected for analysis. Therefore, the evaluation is based upon 56 per cent of the rainfall occurring in this period, certainly a representative sampling. Table 16 shows total precipitation recorded at the Sanitary District remote transmitting rain gages and the Weather Bureau gage for the sixteen rains. That rainfall amounts vary considerably over the metropolitan area is apparent. Table 17 shows maximum 60-minute intensities for each rain gage during the sixteen storms. The official Weather Bureau gage is reported only at clock hours, so the figure is not the actual 60-minute maximum intensity. Table 18 shows maximum 30-minute intensities.

Data acquired during rainfall events occurring in April and May, 1970, have been similarly analyzed. Table 19 shows total precipitation recorded at the nine system gages and at the official Weather Bureau gage. The average precipitation in all system gages for these rains varied from a low of 0.20 inches on April 15, to a high of 1.49 inches on May 21 and 22. Rains varied from being nearly uniformly distributed (May 27, A.M.) to having a ten to one ratio in precipitation totals (April 28). Great diversity in areal distribution of rainfall such as occurred on April 28 are typical of thunderstorms. Uniformly distributed rains are more of a frontal nature. It is interesting to note, in these rains and the sixteen 1969 rains analyzed, that areal diversity in rainfall amount is much more common than uniform or near uniform distribution. Of the 27 rains mentioned, only 8 had maximum gage to minimum gage ratios less than 2 to 1.

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Table 14

HISTORICAL PRECIPITATION DATA

Year	May-September Precipitations, Inches	Per Cent of Normal	Total Annual Precipitation, Inches	Per Cent of Normal
Normal*	16.07	100	24.78	100
1969	9.34	58	19.39	78
1968	23.89	149	37.93	153
1967	12.92	80	25.44	103
1966	13.53	84	24.34	98
1965	25.50	159	39.94	161

*Climatological Standard Normals (1931-1960)

Table 15

1969 MONTHLY PRECIPITATION DATA

Month	Normal*, Inches	1969, Inches	Per Cent of Normal
January	.70	2.05	293
February	.78	.31	40
March	1.53	.90	59
April	1.85	1.55	84
May	3.19	1.98	62
June	4.00	2.93	73
July	3.27	2.95	90
August	3.18	.99	31
September	2.43	.49	20
October	1.59	2.53	159
November	1.40	.65	46
December	.86	2.06	240
TOTAL	24.78	19.39	78
MAY–SEPT. TOTAL	16.07	9.34	58
APRIL–NOV. TOTAL	20.91	14.07	67

Table 16.

TOTAL RAINFALL AT EACH GAGE – 16 1969 RAINS

		Total Precipitation, In.									
Day	Date	US W.B.	UM	VAD	HAZ	FIR	VIL	EDN	MAC	WTP	EUS
116	4-26	.82	.58	.54	.37	.58	.62	–	–	.56	
141	5-21	.18	.23	.04	.22	.16	.20	.14	.10	.08	
148	5-28	.24	0	0	.16	.14	.10	0	.14	0	
173	6-22	.80	.58	.67	.66	1.02	.56	.58	1.06	.61	
176	6-25	.90	1.64	2.02	.80	.92	1.60	1.18	1.11	1.27	
196	7-15	.75	1.04	.08	1.34	.69	1.49	1.30	–	–	
205	7-24	.25	.42	.12	.16	1.04	1.08	.30	.26	.20	
207	7-26	T	.52	1.52	.20	.04	.46	0	0	.44	
211	7-30	.42	.60	.53	.32	.32	.74	.56	.62	.50	
218	8- 6	.71	.51	.56	–	.36	.06	–	1.12	–	
242	8-30	.24	.22	–	–	.26	.22	.26	.26	–	
267	9-24	.28	.26	.14	.20	.32	.24	.28	.50	.24	.16
274	10-1	.14	.06	.05	.12	.07	.06	.08	.08	.05	.05
285	10-12	.69	.97	1.30	–	1.12	.96	1.11	1.12	1.16	.80
303	10-30	.79	1.04	1.00	.66	.60	.68	.66	–	.80	.68
320	11-16	.05	–	.08	.17	.22	.18	.17	.12	.08	.16

Table. 17. MAXIMUM 60 MINUTE RAINFALL AT EACH GAGE – 16 1969 RAINS

Maximum 60 Min. Rainfall, In.

Day	Date	US W.B.	UM	VAD	HAZ	FIR	VIL	EDN	MAC	WTP	EUS
116	4-26	.20	.23	.26	.16	.27	.30	.23	–	.25	
141	5-21	.07	.10	.04	.05	.05	.05	.06	.07	.05	
148	5-28	.24	0	0	.17	.14	.11	0	.15	0	
173	6-22	.20	.23	.20	.19	.49	.18	.16	.39	–	
176	6-25	.56	.79	1.06	.65	.63	.38	.93	–	–	
196	7-15	.59	.92	.06	1.15	.61	.83	1.06	–	–	
205	7-24	.18	–	–	–	–	–	–	–	–	
207	7-26	T	.50	1.53	.20	.04	.30	0	0	.44	
211	7-30	.23	.36	.37	.15	.27	.59	.42	.45	.34	
218	8- 6	.69	.50	.53	–	.36	.06	–	1.12	–	
242	8-30	.12	.12	–	–	.13	.15	.14	.13	–	
267	9-24	.12	.11	.09	.12	.14	.11	.14	.21	.12	.09
274	10-1	.08	.05	.04	.12	.07	.04	.08	.08	.05	.05
285	10-12	.13	.25	.22	–	.12	.20	.16	.22	.22	.18
303	10-30	.10	.16	.18	.17	.11	.10	.12	–	.16	.10
320	11-16	.03	–	.04	.07	.08	.05	.08	.07	.04	.05

Table 18. MAXIMUM 30 MINUTE RAINFALL AT EACH GAGE – 16 1969 RAINS

Maximum 30 Min. Rainfall, In.

Day	Date	US W.B.	UM	VAD	HAZ	FIR	VIL	EDN	MAC	WTP	EUS
116	4-26	–	–	–	–	–	–	–	–	–	
141	5-21	–	.06	.04	.04	.03	.04	.04	.04	.05	
148	5-28	–	0	0	.17	.07	.08	0	.14	–	
173	6-22	–	.12	.14	.11	.30	.09	.12	.24	–	
176	6-25	–	.50	.70	.37	.38	.24	.58	.76	–	
196	7-15	–	.49	.05	1.10	.48	.44	.81	–	0	
205	7-24	–	–	–	–	–	–	–	–	–	
207	7-26	–	.50	1.53	.20	.04	.30	0	0	.44	
211	7-30	–	.25	.22	.09	.14	.45	–	.28	.21	
218	8- 6	–	.49	.53	–	.35	.05	0	1.12	–	
242	8-30	–	.10	–	–	.08	.10	.12	.09	–	
267	9-24	–	.06	.07	.07	.08	.06	.07	.15	.06	.05
274	10-1	–	.05	.03	.11	.05	.02	.08	.05	.05	.04
285	10-12	–	.13	.17	.07	.06	.12	.09	.13	.12	.12
303	10-30	–	.07	.07	.14	.06	.07	.06	–	.09	.08
320	11-16	–	–	–	–	–	–	–	–	–	–

Table 19. TOTAL RAINFALL AT EACH GAGE
11 1970 RAINS

Total Precipitation, In.

Day No.	Date	U.S.W.B.	UM	VAD	HAZ	FIR	VIL	EDN	MAC	WTP	EUS
102-103	April 12-13	.34	–	.42	.59	.58	.70	.58	.48	.45	.26
105	April 15	.11	–	.21	.11	.20	.29	.26	.14	.31	.10
109	April 19*	1.38	–	1.34+	1.36+	1.02+	1.04+	1.13+	1.36+	1.46+	1.42
112	April 22	.31	–	–	.31	.27	.55	.52	.48	.50	.62
118	April 28	.14	–	1.56	.36	.52	.73	.63	.16	1.45	.25
120-121	April 30-May 1	.67	.72	.69	.82	–	.57	.76	–	.73	.67
141-142	May 21-22	1.10	1.37	1.19	1.73	1.57	1.78	1.33	1.25	1.35	1.84
147	May 27	.44	.43	.41	.51	.47	.57	.44	.56	.49	.46
147-148	May 27-28	.58	.44	.27	.51	.38	.56	.59	.69	.55	.42
149	May 29	.41	.83	.85	.39	.57	.35	.11	.51	.17	.83
151	May 31	.77	.24	.15	.11	.20	.54	.45	.84	.42	.43

*Rainfall weight in 7 gages exceeded transmitter range so exact total amount was not measured.

Table 20 shows the maximum 60 minute accumulations at the nine system gages. Intensity influences very greatly the overflow losses that occur. A short high intensity rainfall can cause more combined sewer overflow than a less intense rain having a much greater total accumulation of rain.

Regulator Performance

For each selected rainfall event, a compilation of data was arranged. Listings of data files for regulators, interceptors, rain gages, and river monitors were generated on the line printer. A plotting routine has been written for the system, and the data was plotted, making review and interpretation easier. Knowing the depth of flow in the trunk sewer and the height of the dam or diversion weir, one can determine whether overflow occurred and its duration. Volumetric flow rate of the overflow can be calculated using a weir equation. The analysis of data proceeded approximately as follows:

1. Gate position and Fabridam inflation pressure were checked since both have an effect on depth of flow in the trunk sewer during a storm flow period.
2. If the Fabridam was inflated, the duration of the overflow, if any, was determined and noted.
3. Assuming that the old diversion weir was still in place, the duration of overflow that would have occurred was determined and noted.
4. In instances where the Fabridam was not in an inflated state during the storm flow or where it deflated during the storm flow, an attempt was made to arrive at an estimate of overflow duration based upon the trunk level data, the rainfall data, the flow at other regulators, and the past behavior of the particular regulator. Estimates were made and

Table 20. MAXIMUM 60 MINUTE RAINFALL
AT EACH GAGE – 11 1970 RAINS

Maximum 60 Min. Rainfall, In.

Day No.	Date	U.S.W.B.	UM	VAD	HAZ	FIR	VIL	EDN	MAC	WTP	EUS
102-103	April 12-13	.05	–	.12	.12	.06	.16	.16	.13	.10	.04
105	April 15	.05	–	.09	.06	.08	.12	.12	.06	.10	.05
109	April 19	.38	–	.56	.51	.42	.40	.38	.44	.46	.38
112	April 22	.23	–	–	.18	.14	.34	.41	.40	.31	.52
118	April 28	.11	–	–	.21	.42	.69	.32	.13	1.34	.13
120-121	April 30-May 1	.11	.17	.12	.16	–	.06	.12	–	.12	.14
141-142	May 21-22	.88	.56	–	–	.77	.61	.70	1.01	.59	.67
147	May 27	.22	.16	–	.18	.21	.18	.20	.25	.15	.16
147-148	May 27-28	.32	.20	.14	.30	.12	.23	.24	.38	..22	.15
149	May 29	.26	.54	.57	.29	.52	.13	.04	.33	.06	–
151	May 31	.40	.16	.07	.05	.10	.45	.24	.41	.15	.32

used in overall data compilation only if conditions indicated that accurate interpretation could be made.

When an inflated dam was the diversion weir, volumetric flow calculations for the old weir condition could not be calculated using the weir equation. Applying an orifice equation to the gate opening could, however, produce a figure for additional flow volume diverted because of the higher head condition in the trunk sewer.

Table 21 shows regulator performance as measured by reduction of incidence of overflow during the 16 1969 rains. The figures cited for incidence of overflow are totals for all monitored regulators. Table 22 shows regulator performance as measured by reduction in duration of overflow during the same rains. That many of the per cent reduction figures are high confirms that in the past, with diversion weirs only slightly higher than dry weather flow depth, regulators overflowed for a fairly long period following most rains. Table 23 and Table 24 show the reductions in overflow incidence and overflow duration during the eleven 1970 rains analyzed.

Table 21
SUMMARY OF 1969 OVERFLOW INCIDENCE REDUCTION

		Number of Regulator Overflows		
Day	**Date**	**Pre-Project Conditions**	**Post-Project Conditions**	**% Reduction**
116	April 26	13	1	92
141	May 21	8	0	100
148	May 28	6	1	83
173	June 22	14	6	57
176	June 25	15	13	13
196	July 15	15	11	27
205	July 24	13	3	77
207	July 26	11	4	64
211	July 30	12	6	50
218	August 6	13	7	46
242	August 30	8	1	87
267	September 24	10	1	90
274	October 1	5	1	80
285	October 12	9	2	78
303	October 30	8	1	87
320	November 16	7	1	86
	TOTALS	167	59	65

Table 22
SUMMARY OF 1969 OVERFLOW DURATION REDUCTION

		Total Regulator Overflow Hours		
Day	**Date**	**Pre-Project Conditions**	**Post-Project Conditions**	**% Reduction**
116	April 26	37 00	1 30	96
141	May 21	33 00	0	100
148	May 28	7 15	1 00	86
173	June 22	50 00	10 30	79
176	June 25	51 45	11 45	77
196	July 15	43 15	12 45	71
205	July 24	21 30	1 30	93
207	July 26	15 45	2 45	83
211	July 30	41 00	7 30	82
218	August 6	31 30	6 15	80
242	August 30	17 15	0 30	97
267	September 24	20 15	1 30	93
274	October 1	8 00	1 00	87
285	October 12	69 00	2 30	96
303	October 30	61 30	1 00	98
320	November 16	19 30	0 15	99
	TOTALS	527 30	62 15	88

Table 23

SUMMARY OF 1970 OVERFLOW INCIDENCE REDUCTION

		Number of Regulator Overflows		
Day	Date	Pre-Project Conditions	Post-Project Conditions	% Reduction
102 - 103	April 12 - 13	8	0	100
105	April 15	8	0	100
109	April 19	11	8	27
112	April 22	12	6	50
118	April 28	11	8	27
120 - 121	April 30 - May 1	8	3	62
141 - 142	May 21 - 22	13	11	15
147	May 27	11	4	64
147 - 148	May 27 - 28	11	7	36
149	May 29	10	6	40
151	May 31	11	5	55
	TOTALS	114	58	49

Table 24

SUMMARY OF 1970 OVERFLOW DURATION REDUCTION

		Total Regulator Overflow Hours		
Day	Date	Pre-Project Conditions	Post-Project Conditions	% Reduction
102 - 103	April 12 - 13	67 00	0	100
105	April 15	46 15	0	100
109	April 19	111 15	17 30	84
112	April 22	66 45	4 15	94
118	April 28	37 00	11 00	70
120 - 121	April 30 - May 1	102 45	7 00	93
141 - 142	May 21 - 22	66 00	18 15	72
147	May 27	45 30	8 45	81
147 - 148	May 27 - 28	47 30	9 45	79
149	May 29	36 30	5 15	86
151	May 31	29 15	3 15	89
	TOTALS	655 45	85 00	87

Probably of greater interest than the effectiveness of the program in reducing overflow incidence or overflow duration, is a measure of its effectiveness in reducing overflow volume. To avoid the laborious calculations that would be necessary to produce the additional volumes diverted and prevented from overflowing, use was made of the mathematical model. As part of the model, gate movements may be simulated to evaluate effects of operations.

The actual rainfall data from four 1969 rains and three 1970 rains were used as input for the model with diversion weir height varied to simulate both fully inflated Fabridams and the old fixed height weirs. Table 25 shows the results of this analysis for eleven regulators.

The overall volume reduction predicted by the model for these seven rains is 51 per cent. Reductions for individual rains varied from 30 per cent to 98 per cent. It is to be expected that success in reducing overflow would be inversely related to the total runoff generated, and this is confirmed by the model. The rain of Day 218 was very intense and caused a comparatively large runoff volume. Rains of this nature occur only a few times a year. The other rains analyzed by the model are also of higher than average amount, so the gentle, long duration rainfall events are not represented in this analysis. It is in rains of this nature that the overflow can be completely controlled at the modified regulators. Excluding the Day 218 rain, the overflow volume reduction for the other six rains is 73 per cent.

Table 25

OVERFLOW VOLUMES AT ELEVEN REGULATORS FROM MATHEMATICAL MODEL WITH ACTUAL RAINFALL DATA

	Volume of Overflow, CF			
Rainfall Day	**Old Weirs**	**Inflated Dams**	**Additional Volume Diverted, CF**	**Per Cent Reduction of Volume**
207 - 1969	181,100	2,900	178,200	98
211 - 1969	1,095,700	474,000	621,700	57
218 - 1969	3,161,600	2,216,000	945,600	50
267 - 1969	220,700	27,100	193,600	88
147-148 - 1970	568,500	108,000	400,500	81
149 - 1970	397,600	10,400	387,200	97
151 - 1970	522,300	176,300	346,000	66
TOTALS	6,147,500	3,014,700	3,072,800	51
TOTALS (excluding Day 218)	2,985,900	798,700	2,127,200	73

It is interesting to compare the model's predicted results for the eleven regulators with the data accumulated during the actual rainfall event. Table 26 shows this comparison. For some rains, duration reduction closely parallels overflow volume reduction, while for other rains, duration reduction is both greater than and less than volume reduction.

Projected Seasonal Effectiveness

A sufficient number of rains were analyzed that projections of normal seasonal effectiveness of the new regulator control system can be made. The greatest probable source of error involved in scaling up rainfall related overflow data is in evaluating how representative is the data available of the entire normal season. Very likely the rains for which data were analyzed fall on the heavy side of the distribution of rainfall events. This system can admittedly effect good control only for frequent return interval, low intensity rainfall events. Therefore, scaling up measured to seasonal overflow in the same proportion as measured to seasonal rainfall, will indicate poorer than actual overflow reduction success on a seasonal basis. Statistical studies on rainfall return interval primarily deal with one year return interval storms and greater and little information was available for high frequency rainfall events.

So it should be emphasized that overflow control data presented on a seasonal basis are estimated. Because of the low number of rains analyzed volumetrically with the mathematical model, the projection of seasonal overflow volumes and reductions is even more tenuous. Other methods of estimating overall season overflow volumes were used in an attempt to improve the accuracy of the projections.

The previously mentioned 27 rains occurring in both 1969 and 1970 represent a total of 15.59 in. of rain. This figure is the sum of the averages of all system gages in use for each rain. Average total precipitation amounts for the 27 events ranged from 0.07 in. to 1.32 in. The normal precipitation total for Minneapolis-St. Paul during April through October is 19.51 in.

Table 26

OVERFLOW CONTROL MATHEMATICAL MODEL PREDICTION VERSUS REAL DATA INDICATION

	Per Cent Reductions Predicted by Model		Per Cent Reductions Indicated by Real Data	
Rainfall Day	**Overflow Volume**	**Incidence of Overflow**	**Overflow Duration**	**Incidence of Overflow**
207	98	67	81	67
211	57	43	83	60
218	30	22	75	37
267	88	50	85	83
147	81	71	80	36
149	97	89	86	40
151	66	60	89	55

Table 27 indicates that 164 incidents of combined sewer overflow discharge and over 1000 combined sewer overflow hours were prevented during the 27 rains, reductions of 58 and 88 per cent over what would have occurred had pre-project conditions existed at the major regulators. The overflow incidents and durations were multiplied by the ratio of seasonal to measured rainfall to produce estimated seasonal figures.

Table 27

PROJECT EFFECTIVENESS IN REDUCING FREQUENCY AND DURATION OF OVERFLOW

	Total 27 Rains [a]	Normal Season [b]
Average Total Rainfall, In.	15.59	19.51
Pre-project overflows		
Number	281	352
Duration, hours	1183	1480
Post-project overflows		
Number	117	147
Duration, hours	147	184
Reduction (per cent) in overflow due to project		
Number	58	58
Duration	88	88

[a] measured values

[b] estimated values

Results from computer analysis of actual rainfall data using the mathematical model routines have already been presented in Table 25. At eleven regulators during these seven rains a total of 3,072,800 cubic feet of combined sewage was prevented from overflowing and was intercepted. Comparison of routed interceptor flow hydrographs near the end of the Joint Interceptor for simulated pre- and post-project conditions suggest that a total of about 4,850,000 cubic feet of combined sewage was captured by the system during these rains. Scaling up this value by the simple ratio of seasonal total rain to measured rain results in an estimate of 31 million cubic feet or 230 million gallons combined sewage overflow volume prevented by the system on a seasonal basis.

The mathematical model, described in greater detail in Part II of this report, attempts to account for all flow which reaches the interceptor system, so that the routing phase of the program will produce hydrographs at the end of the interceptor system that are representative of actual conditions. Since only the major regulators and interceptor inlets were directly modeled, the other smaller regulators and inlets were accounted for by using coefficients representative of the ratio of total tributary area to modeled tributary area for each of the 15 catchments modeled. The model calculates the total inlet volume for any rainfall data and then calculates how each hydrograph is diverted at each of the 15 modeled regulators.

For the seven rains analyzed, the model calculated a total inlet volume of 426 MG. Scaled up to a seasonal figure by the ratio of rainfall amounts, the total inlet volume becomes 2700 MG. This represents the total runoff volume for the combined sewered areas of Minneapolis and St. Paul, since the base or dry weather flow was subtracted. This volume is distributed among approximately 150 combined sewered regulators, but, based upon studies of areas involved, it is estimated that about 70 per cent of the runoff arrives at the controlled major regulators for diversion. Figure 63 shows post-project and pre-project dispositions of the estimated total seasonal combined sewer runoff volume. It should be emphasized that the figures are estimated by the model program which was used in a rough state of calibration. Certain of the numbers shown in Figure 63 are not consistent with those produced by other manipulations of data. For example, the reduction in overflow going to the river from controlled regulators of 230 MG represents a reduction of only 34 per cent. This is much lower than the 51 per cent figure in Table 25. This table was prepared from analysis of eleven controlled regulators for which model predictions seemed most consistent with measured data, so this data is perhaps more reliable.

In defense of the combined sewer system it should be pointed out that a large fraction of storm runoff occurring each year is intercepted and conveyed to the treatment plant. Based on 2700 MG of storm water runoff from combined sewered area, 2160 MG runs off the separate storm sewered area. Only 720 MG of combined sewage reaches the river, 1/3 of the volume discharged from the separate storm sewers. So combined sewage would have to be 3 times as polluted as separate storm sewer water to equal the effect of the storm sewer discharges on the receiving water.

Unfortunately the treatment plant is unable to handle flows in excess of about one half of the capacity of the interceptor at the plant. Therefore most of the additional volume intercepted is bypassed untreated at the plant to protect the plant. Correction of this deficiency will be accomplished in future construction at the plant, and in the meanwhile the pollution of the urban stretch of the Mississippi River is much less frequent and of shorter duration to increase dramatically the acceptability of the river for boating, hiking and other recreation.

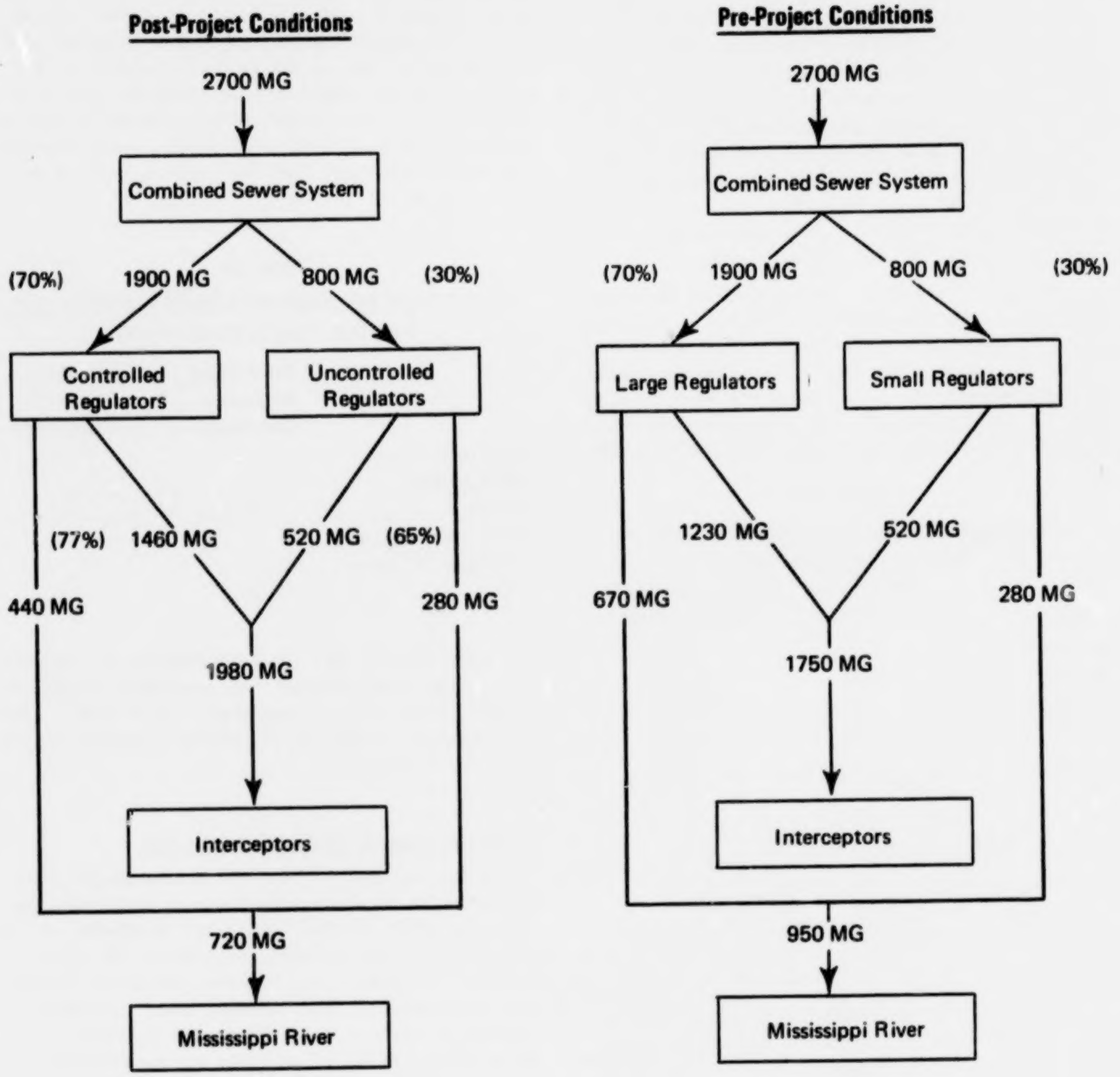
Post-Project Conditions
2700 MG
Combined Sewer System
(70%)
1900 MG
800 MG
(30%)
Controlled Regulators
Uncontrolled Regulators
(77%)
1460 MG
520 MG
(65%)
440 MG
280 MG
1980 MG
Interceptors
720 MG
Mississippi River
Pre-Project Conditions
2700 MG
Combined Sewer System
(70%)
1900 MG
800 MG
(30%)
Large Regulators
Small Regulators
1230 MG
520 MG
670 MG
280 MG
1750 MG
Interceptors
950 MG
Mississippi River

Figure 63. Estimated Disposition of Seasonal Runoff on Combined Sewered areas in Minneapolis and St. Paul.

1970 Spring Thaw

The control and monitoring system was maintained year-round and hourly scanning continued through the winter. Thaws occurring during the winter and spring were capable of causing combined sewer overflow, so it was interesting to note the improvements effected by operation of the system. Operation to increase diversion of combined thaw runoff and sewage is somewhat simpler. Thawing in this climate is usually restricted to daylight hours and usually occurs between 12:00 noon and 5:00 P.M. Thaw flows slowly and predictably rise and fall, there being no equivalent of a "cloudburst," so there is no need to be concerned about deflating the Fabridams to provide needed flow capacity.

The heavy snowcover accumulated in December remained on the ground most of the winter. Table 28 compares December, 1969–March, 1970 snowfall as inches of water with the climatological standard normal precipitation. Figure 64 is the Venturi meter chart for the Minneapolis East Interceptor for February 23, 1970, illustrating a typical thaw runoff pattern.

Table 28

PRECIPITATION AS SNOWFALL FOR WINTER OF 1969-1970

Month	Precipitation Inches - Water	Normal Precipitation Inches - Water
December	2.06	0.92
January	0.47	0.81
February	0.16	0.86
March	2.05	1.52
Total	4.74	4.11

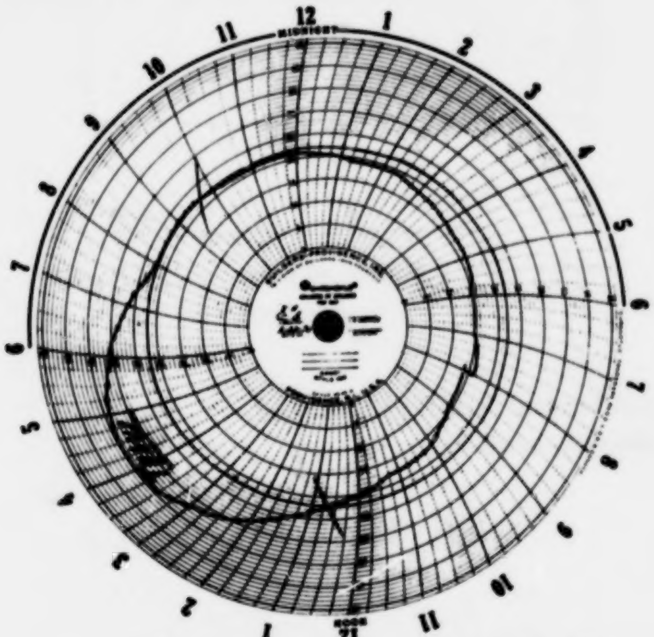

Figure 64. **Flow Meter Chart–Minneapolis East Interceptor (one of two identical parallel meters)**

There were four days on which thawing was extensive enough to cause at least one overflow to the river. There were 26 days, however, on which thawing would have caused overflow at one or more of the same regulators had pre-project conditions existed. Table 29 indicates the amount of thaw overflow that was prevented during the spring snowmelt of 1970. Most of the overflow incidences prevented were probably small and the volumes not great. Seven thaw days produced considerable runoff, however, and substantial volumes of combined flow were kept out of the river by the system.

Table 29

REDUCTION OF COMBINED SEWER OVERFLOW DURING 1970 SPRING THAW

	Pre-Project Regulator Conditions	Post-Project Regulator Conditions
Number of Days Having Thaw Overflow	26	4
Number of Incidences of Regulator Overflow	99	8

About 70 per cent of the incidences of overflow that would have occurred, had pre-project conditions existed, were at four regulators. There were a few regulators for which no pre-project overflows would have occurred at all.

Computer Analysis of Simulated Rainfall

Further use was made of the mathematical model for evaluation of system effectiveness. Rather than use real rain data, rainfall data were simulated. As a simplification, the synthetic rainstorms all were of uniform distribution and intensity. While this type of rain may never in fact actually occur, the analysis provides a means of quantifying what the system may be capable of doing and pointing out the variability of what can be done at various regulators. Each synthetic rain data file was used as input to the model twice—once with the inflated dams as the diversion weirs, and once with the old weirs as the diversion devices. Rainfall lastings 1/4, 1/2, 1, 2, and 3 hours was simulated. Rainfall intensities from 0.10 inches/hour to 1.50 inches/hour were used. Table 30 indicates the various combinations of intensity and duration that were used.

Figure 65 and Figure 66 summarize the results of this analysis. Figure 65 shows that reduction in overflow volume is influenced by both intensity and duration. As duration increases, some limiting overflow

Table 30

SIMULATED RAINFALL DATA USED FOR MATHEMATICAL MODEL ANALYSIS OF THE COMBINED SEWER SYSTEM

INTENSITY, INCHES/HOUR	DURATION HOURS				
	1/4	1/2	1	2	3
0.10			X	X	X
0.20			X	X	X
0.30		X	X		
0.40			X		
0.50		X	X	X	X
0.75		X	X	X	
1.00	X	X	X	X	
1.25		X	X	X	
1.50	X	X	X		

reduction curve would be reached as steady state conditions develop and continue. Figure 66 shows, for rains of one-hour duration, the total overflow occurring at 12 controlled regulators for the two diversion weir conditions. Somewhere between intensities of 0.75 and 1.0 inches/hour, the additional increment of flow that can be diverted appears to become constant, which is what would be expected.

In these analyses, interceptor capacity has not been considered to be a factor. The model, in its routing section, does indicate where it calculates excessive flow in the interceptor; that is, where an input or a routing results in a flow rate exceeding that considered to be the maximum for the interceptor at that location. In processing some of the heavier simulated rainfall, the model did indicate flow volumes exceeding the capacity of the interceptor, but these conditions are not reflected in the figures.

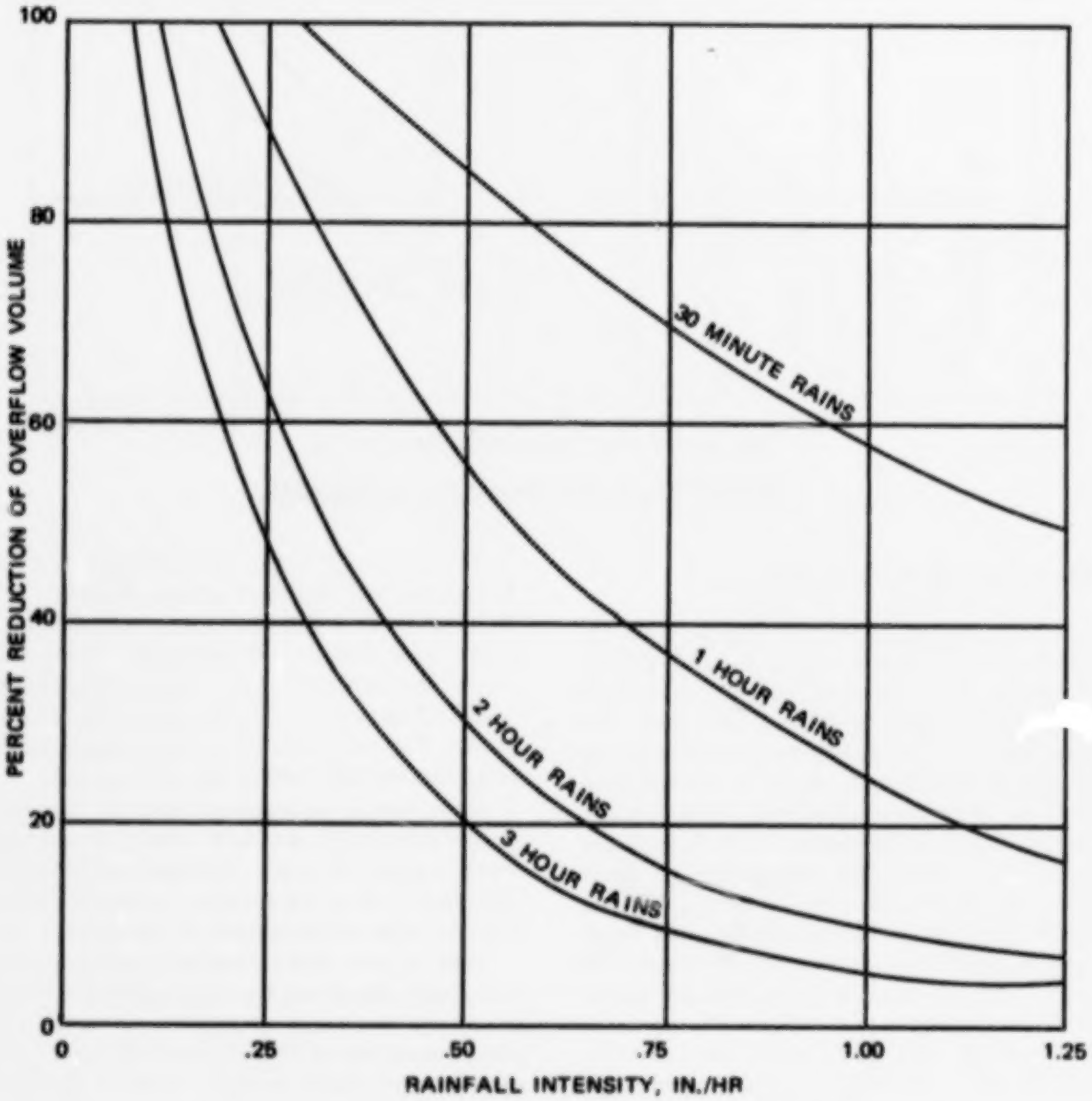

Figure 65. Model Predicted Overflow Reduction

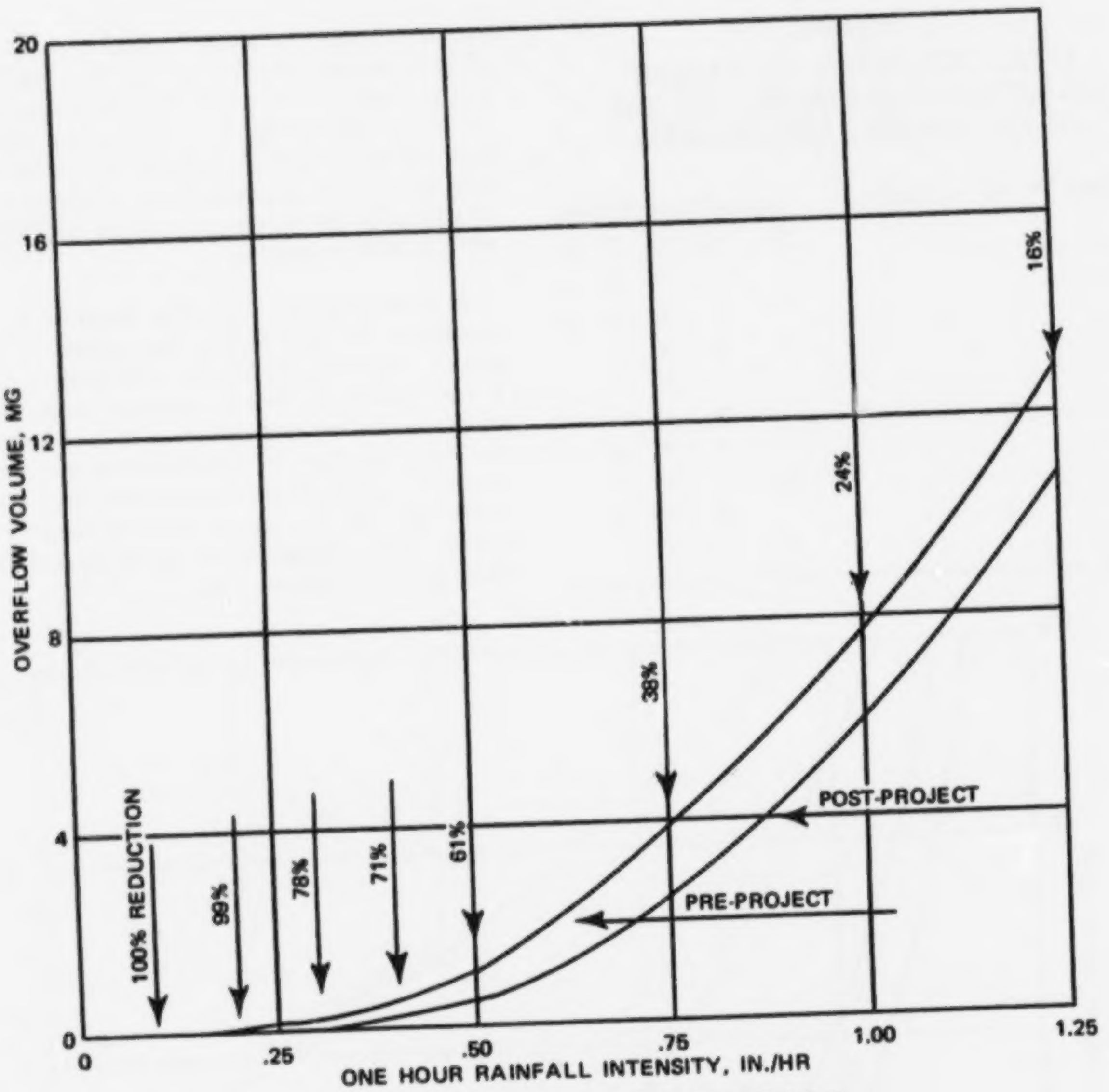

Figure 66. Model Data from Simulated Rainfall

Cost-Effectiveness of the Control System

Using the extrapolated, estimated figures obtained from the mathematical model, approximately 30,000 combined sewered acres produce approximately 720 MG of combined sewer overflow each year. To duplicate the reduction in overflow accomplished by the control system, 230 MG, by separation would then require complete separation of almost 10,000 acres. Estimates of the cost of separation in St. Paul alone are about 400 million dollars, at an average cost of about $20,000/acre. At that cost, the 1.7 million dollar demonstration program is accomplishing the same effect as sewer separation work costing about 200 million dollars. Additionally, this hypothesized separation project would increase the separate storm sewer discharge by about 350 MG each year, thereby increasing storm sewer pollution. Possibly little headway would be made by separating at this very great expense.

The separation cost of $20,000/acre is probably not an overly high estimate either. Guarino et. al. (23) have reported a detailed cost analysis for combined sewer separation in Philadelphia. Their analysis included costs of internal plumbing conversions as well as costs of separation of the collection system in the streets. The total cost of complete separation on a per acre basis was $55,000 to $66,000 per acre.

So it should be assumed that the combined sewer overflow control approach demonstrated here on a small number of major regulators is capable of more than duplicating the results of complete separation at less than one one-hundredth of the cost.

This is even more impressive when one considers that these results can be accomplished in two years. It would be practically impossible to accomplish complete separation of 10,000 acres in 2 years regardless of cost. And whatever the time schedule, separation work would involve infinitely greater inconvenience and commercial interference for the citizens of the cities.

XI. RECOMMENDATIONS

At a meeting in Washington in the Fall of 1968, among other things, the District and FWPCA personnel agreed that it would be worthwhile to empanel a technical review committee representing various fields of engineering interest applicable to the project. The committee's purpose was, as stated in the Board Minutes of October 14, 1968, "to analyze project goals and other program aspects which might lead to suggested modification." The committee, authorized by the Board on February 24, 1969, with members jointly selected by FWPCA and District staff, met at the District's offices on March 17 and 18, 1969. The committee consisted of nationally known experts in research, design, and operation of pollution control facilities.

The committee members were most penetrating in their questioning of the project personnel. In addition to the District project personnel, representatives of the St. Anthony Falls Hydraulics Laboratory who developed the mathematical model, and the District's consulting systems analyst participated in the discussion. A number of changes in the mathematical model and in data management resulted. Several new ideas for evaluation of the effectiveness of the system were obtained.

Not all of the recommendations of this committee were followed because of the need to proceed with the projects' limited objectives. Most of the recommendations are still very pertinent now, as the demonstration period of the project ends and a final report is prepared, and as the continued use and improvement of the system is anticipated. The entire report of the committee follows.

REPORT BY EVALUATING COMMITTEE IN SESSION MARCH 17-18, 1969

The Evaluating Committee named below met on March 17-18, 1969, to review the project entitled "Dispatching System for Control of Combined Sewer Losses" financed jointly by the Federal Water Pollution Control Administration and Minneapolis-St. Paul Sanitary District.

The following members of the Committee participated in the deliberations:

Mr. David R. Dawdy
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U.S. Geological Survey
345 Middlefield Road
Menlo Park, Cal. 94025

Mr. Carmen F. Guarino
Deputy Commissioner
City of Phila. Water Dept.
15th and John F. Kennedy Blvd.
Philadelphia, Pa. 19100

Mr. V. A. Koelzer
Vice President
Harza Engineering Company
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Mr. M. B. McPherson
Program Director
ASCE Urban Water Resources Research Program
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Mr. Stifel W. Jens
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Ben Sosewitz, Acting Chief
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The Metropolitan Sanitary District of Greater Chicago
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The Committee elected as its Chairman, David R. Dawdy, and as its Secretary, Ben Sosewitz.

The following project description was reviewed and is taken from the information sheet prepared by the Office of Research and Development, Federal Water Pollution Control Administration:

DESCRIPTION OF PROJECT: "Dispatching System for Control of Combined Sewer losses."

> *"The project includes preliminary studies to update historic data, a four-phase construction project consisting of installation of a gaging system, a data logger, five river monitors, telemetering rain gages, regulator modifications, and a post-construction program evaluation to include special studies by the University of Minnesota. Existing regulators will be replaced with modern power operated gates at 18 key diversion locations. A supervisory system will be provided to telemeter gate positions, flows, and levels in sewers to be controlled to a central point where a dispatching operator can observe conditions and regulate flow accordingly. Maximum utilization of interceptor sewer capacity would be assured and overflow to the river will be minimized."*

The above mentioned description defined initially the tools to be used in achieving the objectives of this program which are articulated in the last sentence of the project description. It is the consensus of the Evaluating Committee that the approach to achieve this end, as well as the construction work completed and the instrumentation provided, have been coordinated sufficiently to demonstrate successfully the capability of operating remotely and automatically the regulating devices on the interceptor sewer system.

It has also been demonstrated that the collection, storage, and analysis of data describing sewer elevation, gate position, rainfall occurrence and waterways quality monitoring, are on line in accordance with the project description.

The Committee has chosen for its purpose to divide the basic objectives of this project into the following three categories:

1. *operational benefits accruing to the Minneapolis-St. Paul Sanitary District;*
2. *continuity of operational results and data accumulation for future analysis, evaluation and study; and*

3. program concepts and results usefully transferable to other municipalities facing similar problems.

It is the consensus of the Committee that operational benefits may be anticipated by the Minneapolis-St. Paul Sanitary District in the utilization of this system to reduce overflows to the river. No numerical results can be associated with this until after an operational season is completed. The full impact of this system's value can only be expected after the mathematical model being developed is placed into service and coordinated with the system and computer in performance tests. Several suggestions regarding the above follow:

(a) Development of the modeling program should be continued.

(b) It would be desirable to obtain some measurements of discharge inside the system to verify the model.

(c) Other auxiliary field measurements should be obtained to verify the data being monitored by the system.

(d) Pre-project conditions should be simulated and evaluated in order to determine relative comparisons.

(e) Economic evaluation to determine relative effectiveness of the system should be planned for and pursued.

Of greater concern to the Committee was the need for crystalizing data and conclusions which may be transferable and of benefit to other communities. The Committee cautions the Project Director and the Federal Water Pollution Control Administration not to allow the unique opportunity, available as a result of this project, to be dissipated because of lack of completeness or followup. It is the opinion of the Committee that the following steps should be included in the present program or an extension of the program in order to guarantee the value of the transferable data:

(a) The model theory applied in both routing and analysis should be verified operationally and by field measurement.

(b) Simulation of pre- and post-project conditions should be accomplished.

(c) Considerable effort should be placed in reporting out the details of the system used in achieving the operational capability demonstrated.

(d) Any sophisticated economic evaluations should be reinforced by actual field verification. The Review Committee recommends that funds be sought for a new program or an extension of the present program to make such economic evaluations.

It is the feeling of the Committee that prior to final submittal of the report as outlined, a second project review committee should evaluate performance over the operational season, which will commence shortly, together with the responsiveness to the recommendations outlined herewith. Such a committee could bring additional insight if it included independent participants such as a hydraulic modeler, hydrologic modeler, planner, instrumentation specialist and specifically operators from Seattle and Detroit because of the similarity of the project to their activities. In addition, it is suggested that the final report author avail himself of an ASCE report to the USGS (dated April, 1969) which will shortly be available.

In conclusion it is the consensus of the Committee that the project direction has been handled expertly and that in the Committee's opinion, if additional funds are required to establish the continuity and guarantee the value of the project, such expenditure is strongly justified by the opportunity available to meet the industry's needs at the present time.

DRD:rc
April 17, 1969

END OF REPORT

Regarding the four steps recommended in the report to be included in the present program or an extension of the program, the following remarks can be made.

1. The model theory has been verified operationally with real data. This is reported upon in detail in Part II of this report, the report of the Saint Anthony Falls Hydraulics Laboratory to the Minneapolis-Saint Paul Sanitary District. There is, nevertheless, need for additional improvement, calibration, and further verification with more data that has and will be collected. At this time, this is not possible because of lack of funding.
2. Simulation of pre- and post-project conditions has been accomplished to some extent using the existing mathematical model. This is reported upon in both Part I and Part II of this report. One benefit derived from this simulation, besides evaluation of system effectiveness, is that areas of the model requiring improvement are readily identified in analysis of simulation results.
3. Hopefully, this report has adequately reported details of systems used in the Sanitary District Regulator Demonstration Program. If not, personal inquiries and inspection visits will be as welcome in the future as were the many occurring in the past.
4. Sophisticated economic evaluations have not been made.

Many recommendations regarding the data collection aspects of the system have been received. The following are selections from personal correspondence to the Executive Director-Chief Engineer and the Project Engineer at the Minneapolis-Saint Paul Sanitary District from review committee members and others.

> "Both you and your staff are to be congratulated on the progressive policy which you are following concerning water pollution control. There are a lot of words being spoken these days about necessary advances in our field, but not as many deeds. Your organization is matching your words with deeds."
>
> Carmen F. Guarino, Deputy Commissioner, Water Department, City of Philadelphia. March 19, 1969.

> "You are indeed fortunate in having pursued so vigorously this inovation in the control of overflow from a combined sewer system. The detail to which this project has been carried and the enthusiasm expressed by its staff were particularly impressive."
>
> Vinton W. Bacon, General Superintendent, Metropolitan Sanitary District of Greater Chicago. March 28, 1969.

> "The opportunity for collecting the additional data by proper supplementary instrumentation and network design for one or more of the catchments involved in the Minneapolis-St. Paul demonstration project . . . is so great that to ignore it appears indefensible . . .
>
> Local operational and probable design benefits will accrue from a verified or modified mathematical model."
>
> Stifel W. Jens, Reitz and Jens, Consulting Engineers. April 12, 1969.

> "The approach taken here certainly does have applications in the other metropolitan areas. If the older cities are required to eliminate or minimize stormwater overflows, they will have to choose between various alternatives and combinations. The experience of the Minneapolis-St. Paul area will be extremely helpful in this regard.
>
> To attempt separating sewers in large cities would be a tremendous undertaking and, needless to say, very expensive . . .
>
> The information which will be collected by the system that Minneapolis-Saint Paul has installed . . . will be helpful to determine the best methods of minimizing stormwater pollution, proper design of collector systems, and the practicality of routing storms through a collector system."
>
> Carmen F. Guarino, Deputy Commissioner, Water Department, City of Philadelphia. April 13, 1969.

> "Although Mr. Sosewitz's report emphasized the need for contining the data collection program, I am so convinced of the unique opportunity available in your project to obtain data that are otherwise sadly lacking, that I feel continued re-emphasis of this aspect is essential. This alone would justify future additional grants from FWPCA or Office of Water Resources Research."
>
> V. A. Koelzer, Chief, Engineering and Environmental Sciences, National Water Commission. May 1, 1969.

> ". . . a point . . . was made by our evaluating committee . . . that, in the light of the very meager amount of data on quantity and quality of wastewater flows, the unique installation which you have should continue to generate information which will be of widespread public value. It would be very disappointing, in my view, for the information system to be used for purely operational purposes."
>
> V. A. Koelzer, Chief, Engineering and Environmental Sciences, National Water Commission. December 22, 1969.

To the words of these people, the Project Engineer can only add the statement that the Minneapolis-Saint Paul Sanitary District has been deeply impressed by these recommendations. Certainly, efforts will continue to be made to accumulate much needed data, but to insure transferability of data, guidance and direction must come from without.

A report to the United States Geological Survey by the American Society of Civil Engineers also emphasized the importance of data similar to that which the Sanitary District system can continue to collect.

> "Extensive construction of new and replacement urban drainage systems and facilities for reduction of pollution from storm discharge and combined sewer overflows over the remainder of this century will involve significant national expenditures. Existing knowledge is inadequate for efficient and optimal planning and development of such facilities. Better methods of analysis and more realistic design criteria are needed for engineering design of new drainage systems."
>
> "Improved methods are evolving very slowly because of a dearth of field measurements of rainfall-runoff from which logical, reliable models and quantification of their principal parameters can be developed. No municipality has had the financial and manpower resources to mount a research program suited for national transferability of results, and currently no prospect is in evidence of a consortium of local governments financially prepared to undertake the task." (9)

Very likely the Sanitary District system would have to be modified to increase its value as a source of basic data needs. Again, impetus must come from without.

Other recommendations can be made. In all probability, systems similar to the one used at the Minneapolis-Saint Paul Sanitary District can be used with similar success elsewhere.

"Of the fourteen largest U.S. cities, ten are partially or wholly served by combined systems of sewerage: New York, Chicago, Philadelphia, Detroit, Cleveland, Washington, St. Louis, Milwaukee, San Francisco and Boston. Of these, the following are served almost exclusively by combined systems: Chicago, Detroit, St. Louis and San Francisco; and more than half of New York, Philadelphia and Cleveland are served by combined systems." (9)

Several years ago, the American Public Works Association (21) estimated the national construction cost for eliminating combined sewer systems by separation at $48 billion. Because of the extreme cost and the impracticality of separation, along with evidence that urban storm water discharges from separate storm sewers is signficantly polluted, the FWQA has promoted research and demonstration studies of alternative methods of combined sewer overflow pollution abatement, of which the Minneapolis-Saint Paul Sanitary District Regulator Demonstration Program is one.

The approach used here, one of control and routing, would seem to be applicable elsewhere to achieve limited but more immediate results at proportionally low cost and to complement other alternative methods by which more complete abatement might be attained.

Any treatment facility built on a controlled regulator system, such as that in Minneapolis and St. Paul, would accrue these benefits from the existing system: Its size could likely be smaller; it could be accurately sized because of data already available; and operating and maintenance costs would be lower because of less frequent utilization.

Another fact worthy of mention is that this was really a "first of a kind" project. Much has been learned here, and in other similar projects elsewhere, that should permit subsequent systems, having greater capabilities, to be installed elsewhere at lower cost. Engineers at Badger Meter Manufacturing Company have indicated, in private conversation, that the system they provided the Sanitary District with could be acquired at a lower cost today both because of what was learned during this project and because of advancing technology. The central processor, or computer power, of this system could be provided today at a much lower cost than three years ago.

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XIII. ACKNOWLEDGEMENTS

The author of the report wishes to acknowledge the help and cooperation of the Board and Staff of the Metropolitan Sewer Board and the former Minneapolis-Saint Paul Sanitary District.

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MAURICE L. ROBINS, P.E., Executive Director-Chief Engineer, MSSD (July, 1968 to Present)

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Assistant Engineer, June, 1967-July, 1969
JAMES J. ANDERSON, P.E., Project Engineer, April, 1966-July, 1969
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Consulting Programmers

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Mathematical Model Program Personnel

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GARTH A. HARRIS, Post Doctoral Fellow, University of Minnesota
ARTHUR F. PABST, Research Fellow, University of Minnesota

Plans and Specifications

Contract 664A – Pioneer Service & Engineering Co., Chicago
Contract 664B – Pioneer Service & Engineering Co., Chicago
Contract 666 – Pioneer Service & Engineering Co., Chicago
Contract 677 – Toltz, King, Duvall, Anderson & Assoc., St. Paul

Contractors

Contract 664A – George F. Cook Construction Co., Minneapolis
Contract 664B – Badger Meter Mfg. Co., Milwaukee
Contract 666 – Fairchild Camera and Instrument Co., New York
Contract 677 – Acton Construction Co. and Ashbach Construction Co., a joint venture, St. Paul

Special Consultants

Mathematical Model Program–Saint Anthony Falls Hydraulics Laboratory, University of Minnesota, Minneapolis

Cooperation by others

The District has enjoyed excellent cooperation from many local, state, and federal agencies, numerous private firms, and private individuals. A complete list and all the details here would be too lengthy, but a brief summary follows with apologies for unintentional omissions.

Federal Water Pollution Control Administration

This project has been authorized, supported, and financed in part, by the Department of Interior pursuant to the Federal Water Pollution Control Act.

The fine assistance and cooperation from the personnel of the FWPCA is greatly appreciated. Discussions on various matters with Washington and local personnel always provided quick resolution to problems and yielded information requested immediately. The river quality monitors are as developed by the FWPCA, with considerable help locally and from Cincinnati. STORET personnel have been very knowledgeable and helpful, and the effectiveness of the system which the FWPCA has developed can hardly be overstated.

Without the financial assistance from the FWPCA, the project might not have existed.

U.S. Geological Survey

The USGS has furnished data for the project, both locally and in Washington, promptly and exactly as requested.

ESSA

The U.S. Weather Bureau has assisted the daily regulator surveillance by providing direct rainfall information and the state climatologists have assisted in the placement and checking of rain gages. They have also made publications and rainfall data available, some of which has been placed on punch cards for correlation with MSSD data.

Corps of Engineers

The Corps of Engineers has provided data and maps, and computer programs developed by them have been used in the project.

Cities of Minneapolis and Saint Paul

Both Cities are providing financing for the District's share of works constructed exclusively for one city and the cost of the District's share of jointly used project facilities is financed by them through normal District procedures. The engineering departments in both cities have provided plans and drawings and obtained necessary approvals, in addition to maintaining close liaison on other matters.

The Water Departments in both cities have allowed installations of rain gages on their property. One river quality monitor is installed in a building at the Minneapolis Water Department. The Saint Paul Fire Department has cooperated in the installation of a rain gage, as has the Metropolitan Airports Commission. A river quality monitor is located at one of Saint Paul's storm water pumping stations.

Private Firms and Individuals

Northern States Power Company has allowed installation of a river monitor on their property at the High Bridge Plant. They also have been most cooperative in providing electrical services at all of the locations, including some in unusual locations.

Northwestern Bell Telephone Company personnel have been extremely helpful and have maintained close liaison with District and contractor personnel. When required, all parties have worked very effectively as a team.

Industrial Molasses Corporation and Svoboda Boat Works have allowed river monitors to be placed on their property.

Manufacturers, vendors, sales representatives and contractors in all fields have taken an interest in this unusual project and have provided help even when no direct benefit to them could be realized.

American Society of Civil Engineers

The ASCE Urban Hydrology Research Council has made available the results of extensive research and publications concerning combined sewer overflow problems sponsored by the FWPCA and concerning urban hydrology and water resources management sponsored by the USGS and OWRR, respectively. The interchange of information at meetings and in the Division Journals has been invaluable to the project.

APPENDIX A

An Example of Data, May 27-28, 1970

Presented as an appendix is a nearly complete set of plotted data for a single rainfall event. The data are typical of the quality and quantity of data available for 27 rainfall events. By the end of the 1970 rainfall season, this body of data will likely have grown to include over 50 rainfall events.

With this large collection of high quality data, the calibration of the existing mathematical model can certainly be improved. This data, which because of the procedures that have been set up can continue to accumulate, will be of great value to the Public Works Departments of the cities of Minneapolis and St. Paul or to their consultants as they face the continuing problems of controlling pollution from their combined sewer systems.

The data are presented in the form of plots or graphs that were generated on the project system. The time axis on all plots is 16 hours long, from 1600 hours on Day 147 (May 27) to 0800 hours on Day 148 (May 28). Each vertical grid line represents one hour. The vertical axis on all plots is labeled from 0 to 100, representing 0 to 100 percent of the full scale value that is printed at the top center of each plot. Raingages and inflatable dam pressures have full scale values of 2 in. and 2 psi respectively. Full scale values for depth of flow may be 50, 100, or 120 in.

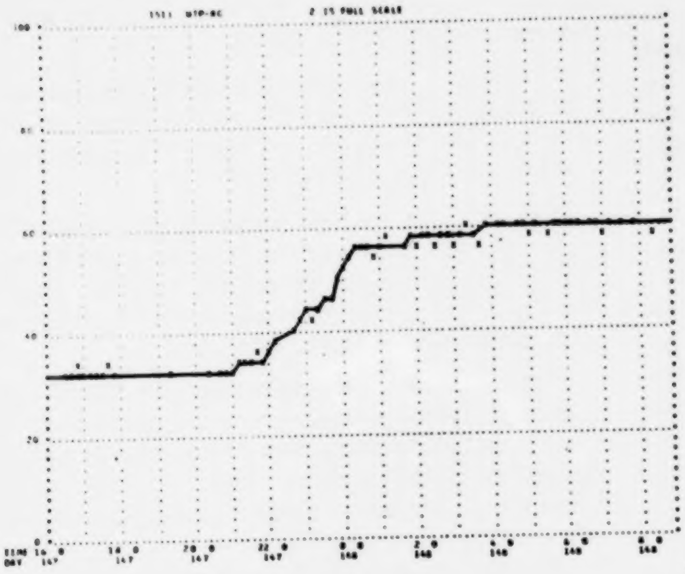
On plots of trunk level (TL) the horizontal row of 2's represents the height of the old pre-project diversion weir and the horizontal row of 1's represents the height of the new inflated dam.

The rain for which the data are presented was fairly uniform. Rain began falling at about 2100 hours on May 27 and lasted, on the average, about 3 hours. The total rainfall amount measured at the 9 system rain gages varied from 0.27 in. to 0.69 in.

Review of this data indicated that there were 7 overflows from control and monitoring regulators and that there would have been 11 overflows had pre-project conditions existed. Total overflow duration hours for pre-project conditions would have been 47.5 and the actual total overflow hours were only 9.7, so at controlled regulators 37.8 overflow hours were prevented.

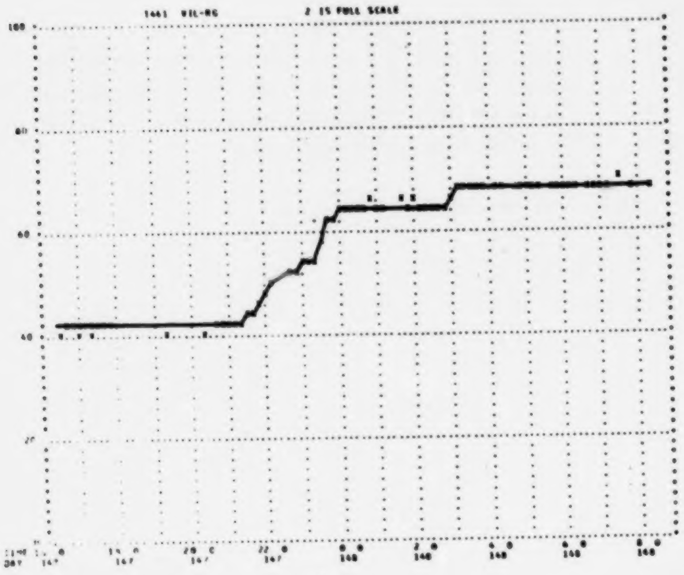
When the rainfall data were input to the mathematical model, the overflow volume reduction attributable to the program at eleven well modeled regulators was from 568,500 cubic feet to 108,000 cubic feet, a reduction of 81 per cent.

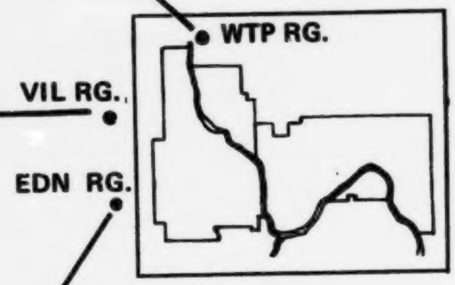
RAIN GAGES

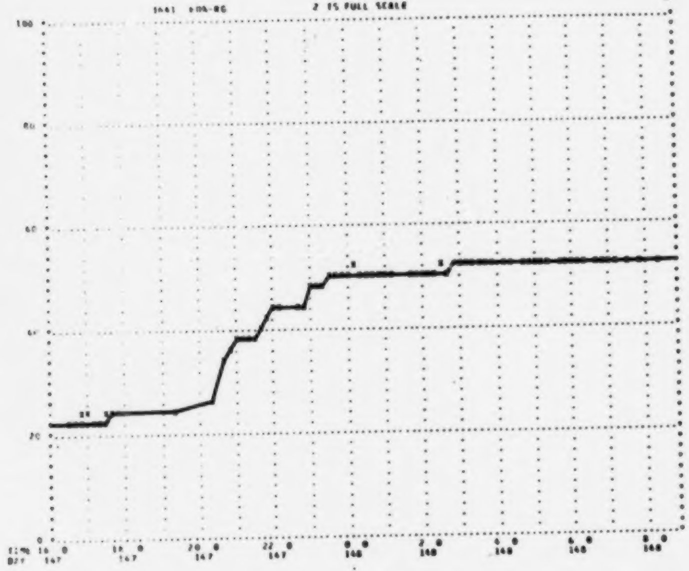


The total amount of precipitation at the Water Treatment Plant rain gage was .55 inches.

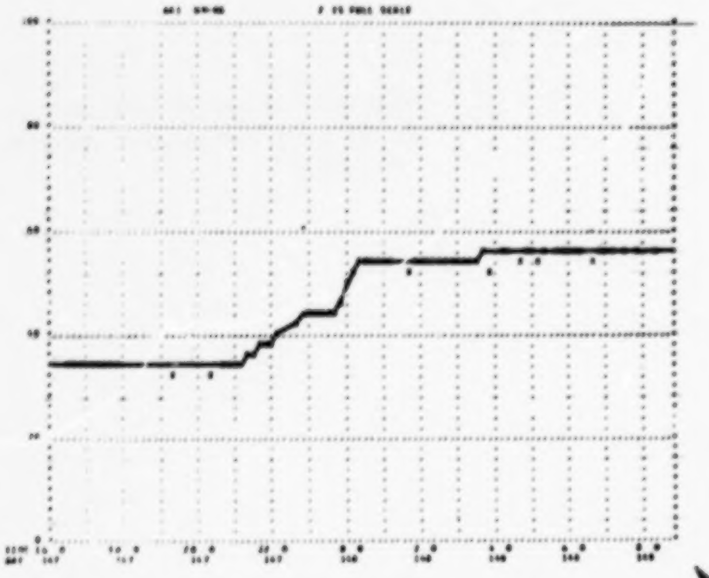
The total amount of precipitation at the Golden Valley rain gage was .56 inches.





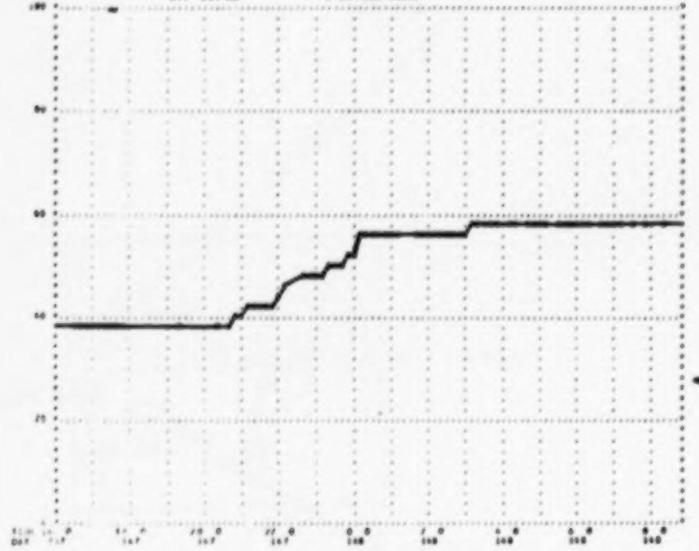


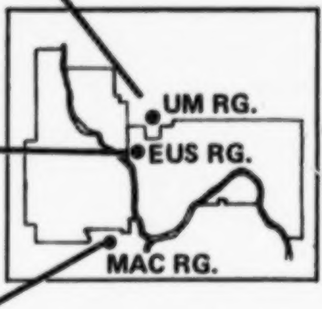
The total amount of precipitation at the Edina rain gage was .59 inches.

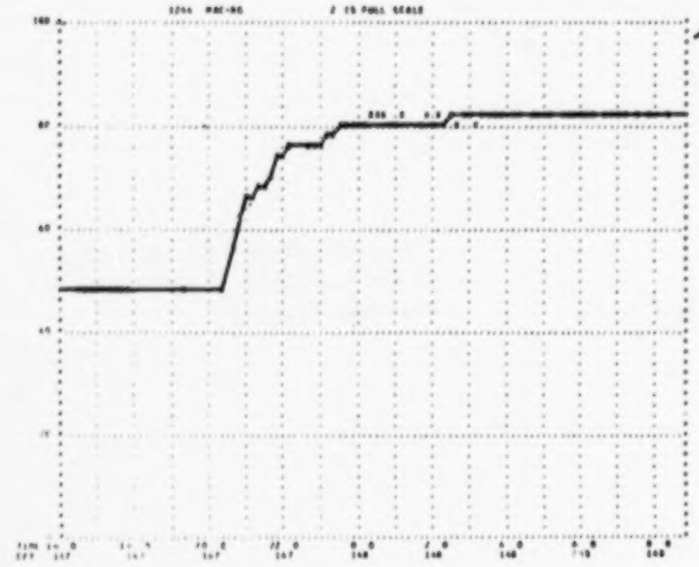


The total amount of precipitation at the University of Minnesota St. Paul Campus rain gage was .44 inches.

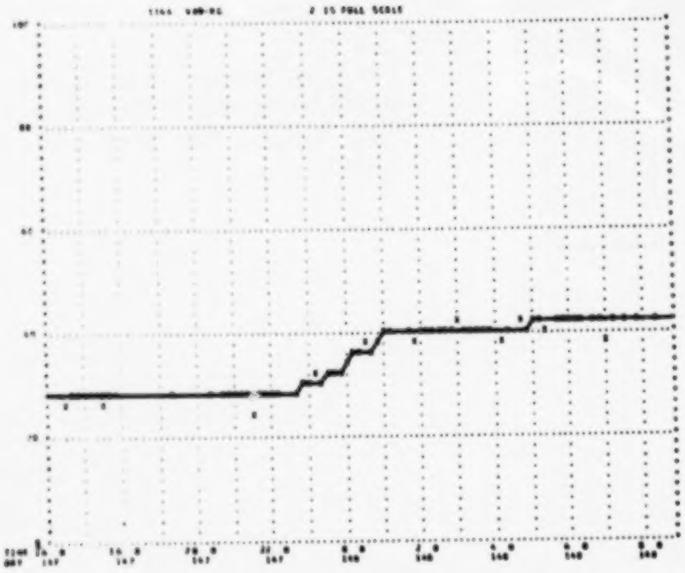
The total amount of precipitation at the Eustis rain gage was .42 inches.



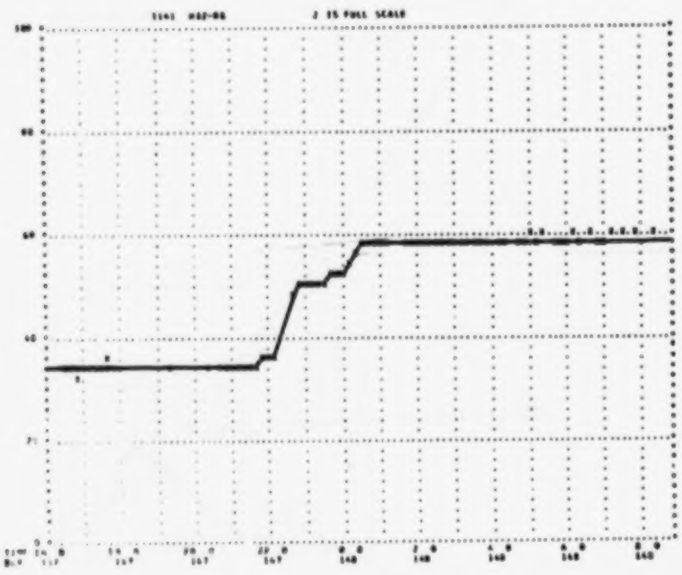




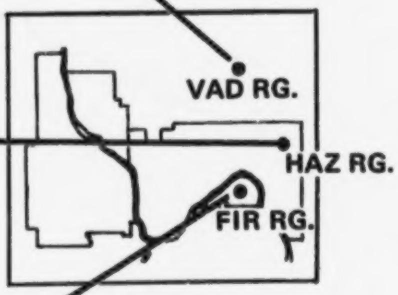
The total amount of precipitation at the Airport rain gage was .69 inches.

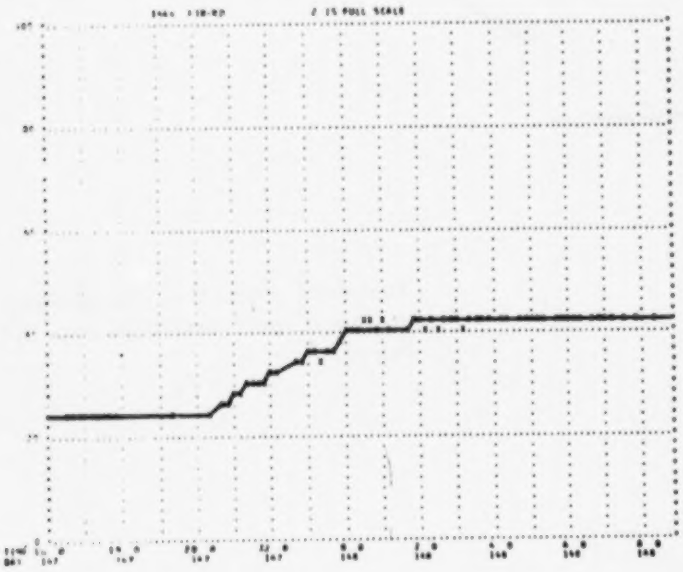


The total amount of precipitation at the Lake Vadnais rain gage was .27 inches.



The total amount of precipitation at the Hazel Park rain gage was .51 inches.



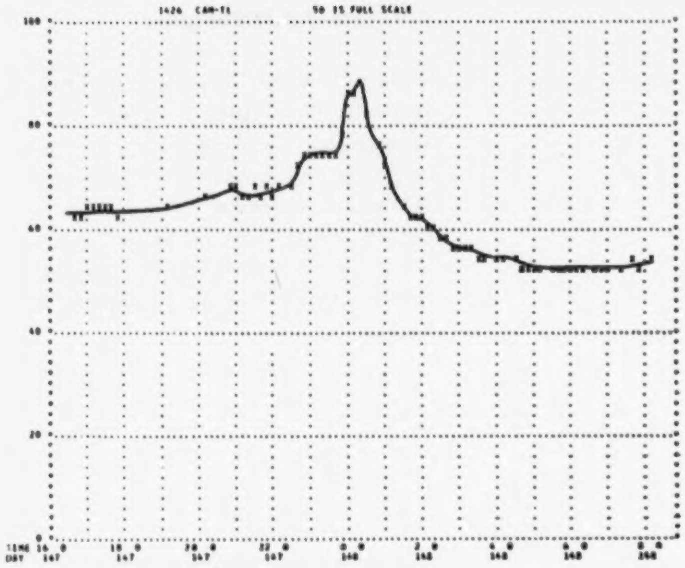


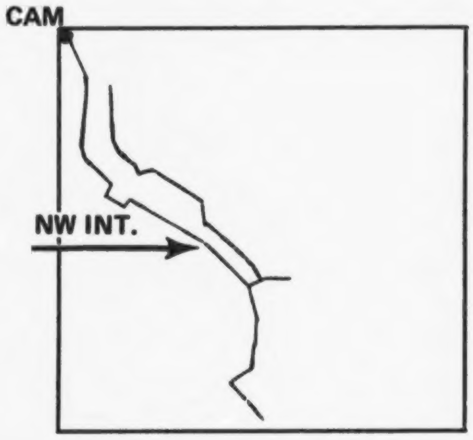
The total amount of precipitation at the West Side Fire Station rain gage was .38 inches.

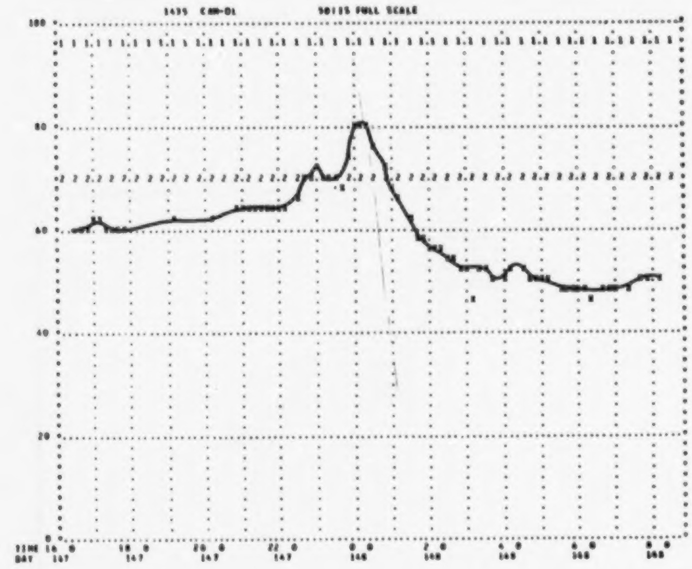
REGULATORS

Camden Regulator

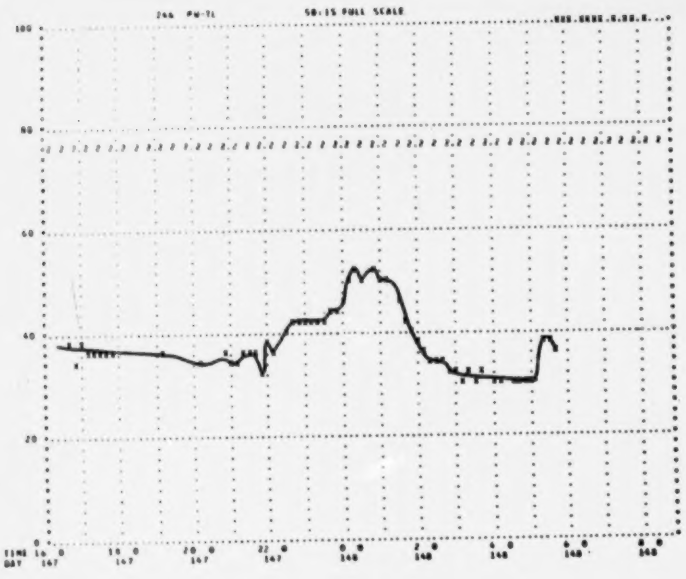
The increased depth of flow caused by rainfall is apparent in this plot. The pipe height is 48 inches.





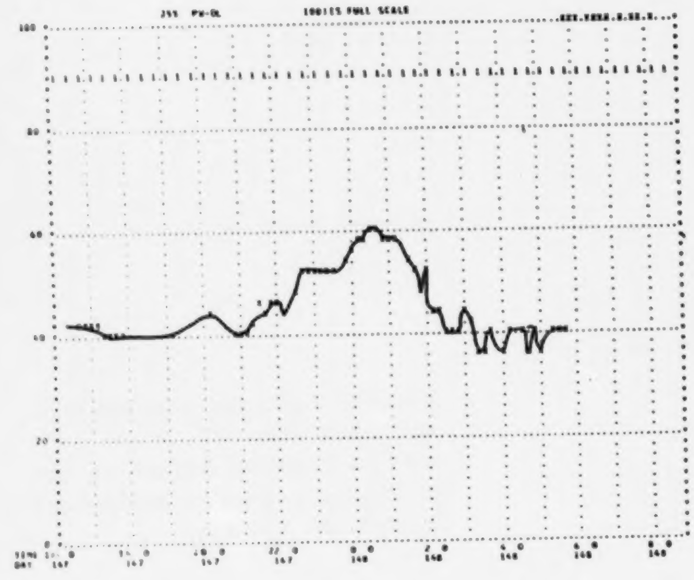


The height of a side overflow weir was raised from 35" to 48". No overflow occurred, but before this modification, overflow would have occurred for 1.5 hours.

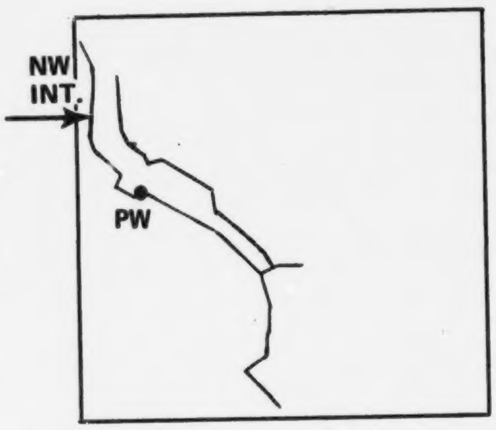


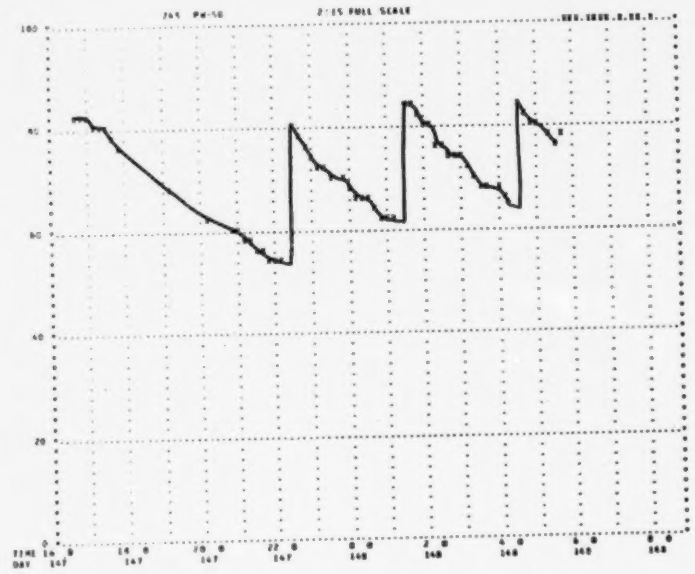
Portland and Washington

This is termed "Master Regulator" because it is built into the N.W. Interceptor, and regulates all flow entering the interceptor upstream. Although increased flow was received here, no overflow would have occurred even before regulator modification. The pipe height is 90 inches.

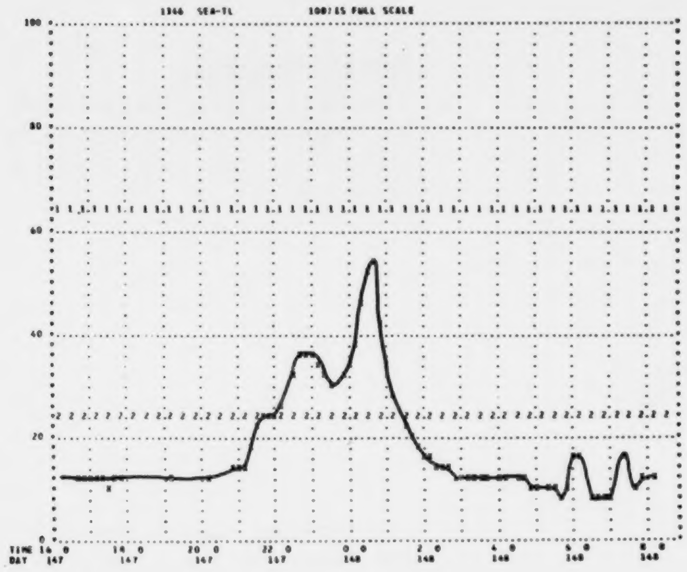


The same proportionate increase in flow is apparent in the interceptor down stream from this regulator.



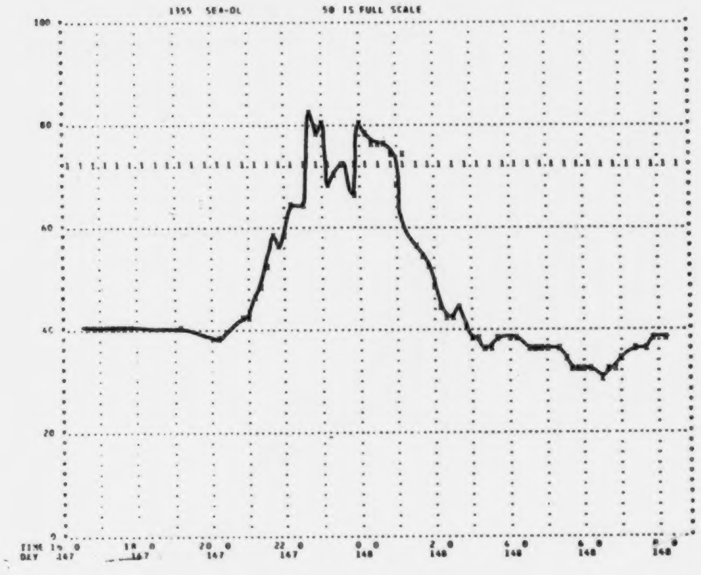


The vertical lines represent automatic inflation of the 'Fabridam'. The pressure losses due to leakage cause no problems. Within the range of pressure shown, there is no change in height.

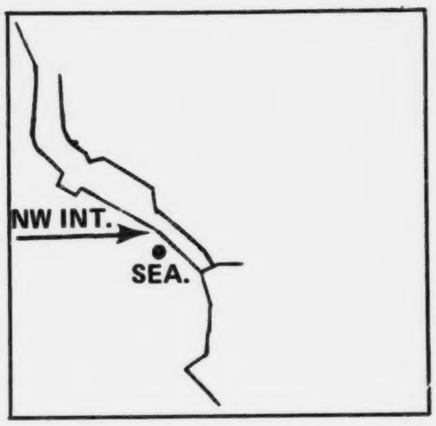


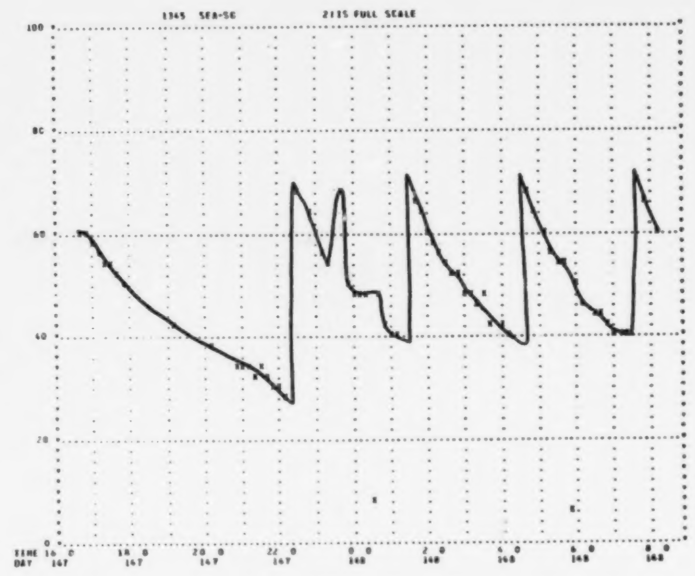
26th and Seabury

This regulator would have overflowed for 3.5 hours prior to installation of the Fabridam. The pipe height is 96 inches.



This depth is measured in the dry weather outlet chamber. The outlet pipe size is 36 inches, and submerged entrance conditions existed for over 1.5 hours.

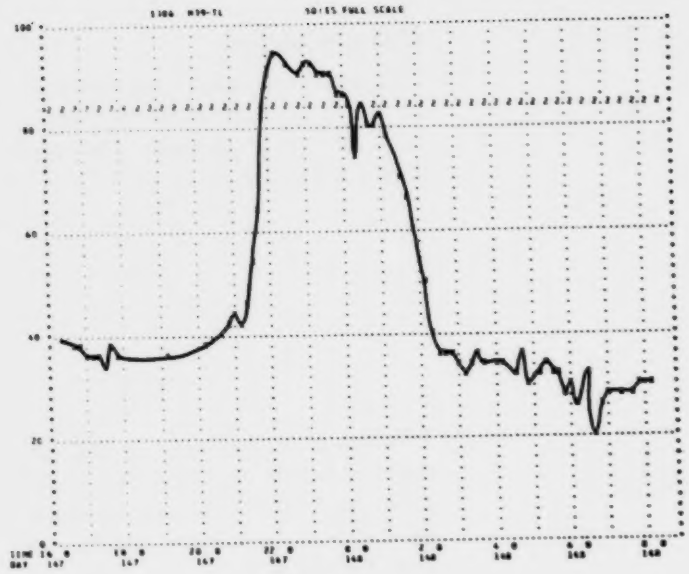




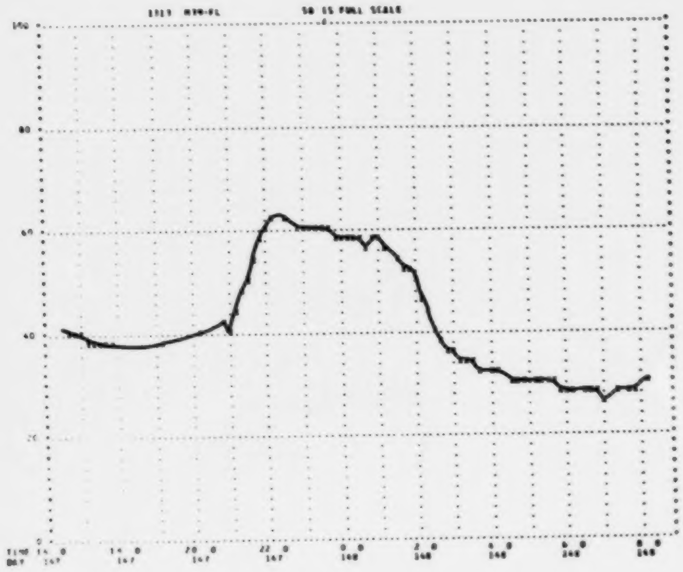
This plot shows the automatic inflation pressure adjustment at three hour intervals and the increased pressure exerted upon the 'Fabridam' during high flow periods.

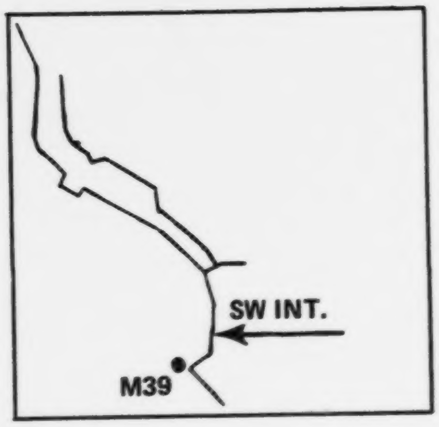
39th and Minnehaha

The depth of flow here exceeded the height of the old weir for 2.25 hours. The trunk sewer height is 123 inches.

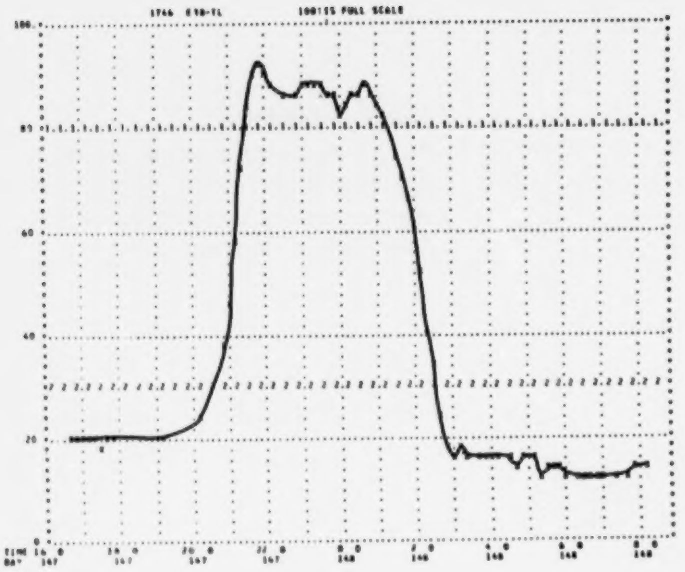


The increased flow in the outlet pipe leading to the interceptor is shown. The level sensor is located within a parshall flume, so the discharge can be determined here.



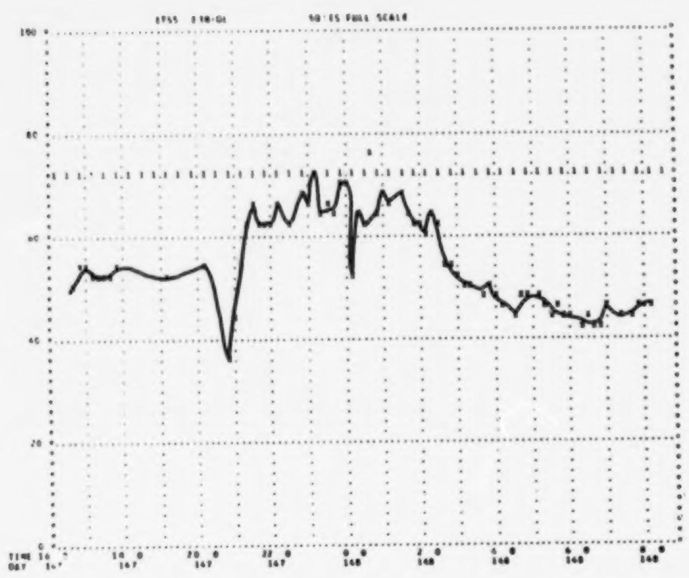


Due to damage the 'Fabridam' was not functional.

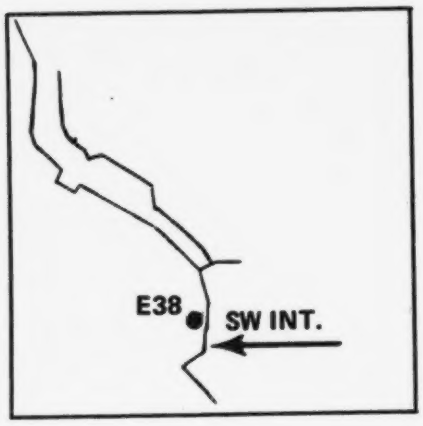


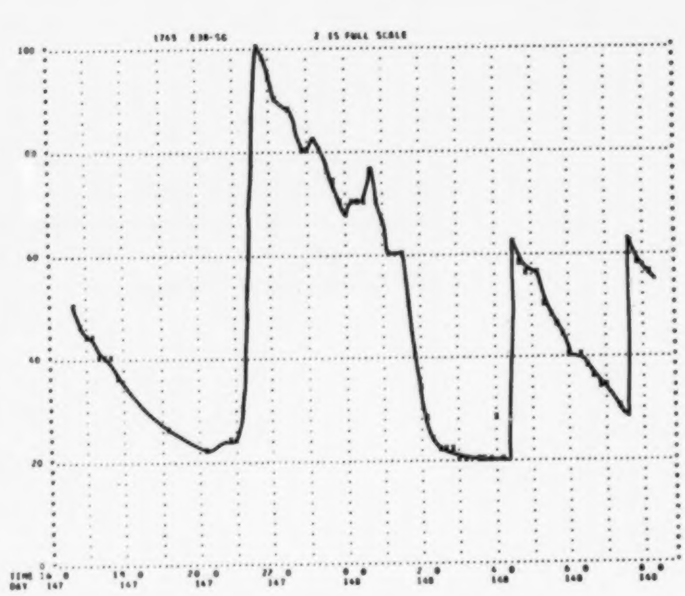
38th and Edmund

During this rainfall event, flow exceeded the height of the inflated 'Fabridam' for four hours. A much greater volume would have been lost over the old weir which was overflowed for six hours. The height of the pipe is 120 inches.

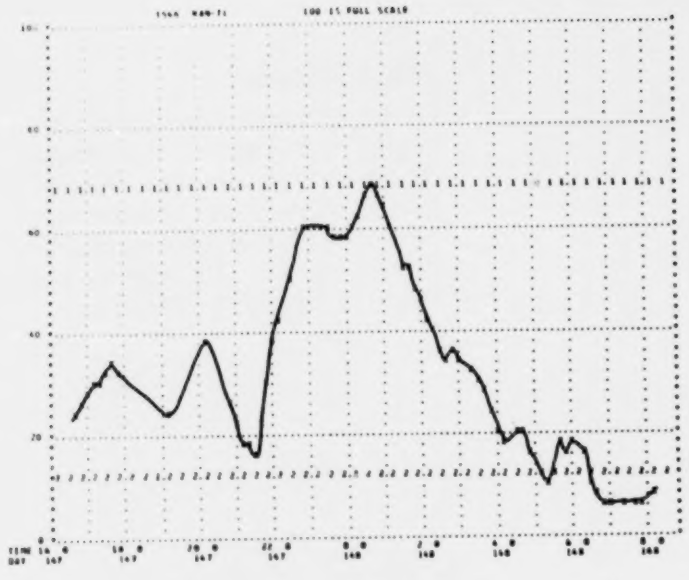


The 36 inch outlet pipe here did not flow full, indicating that the size of the gate opening controls the maximum diversion rate.



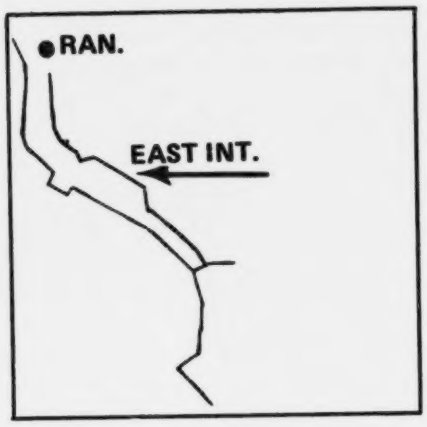


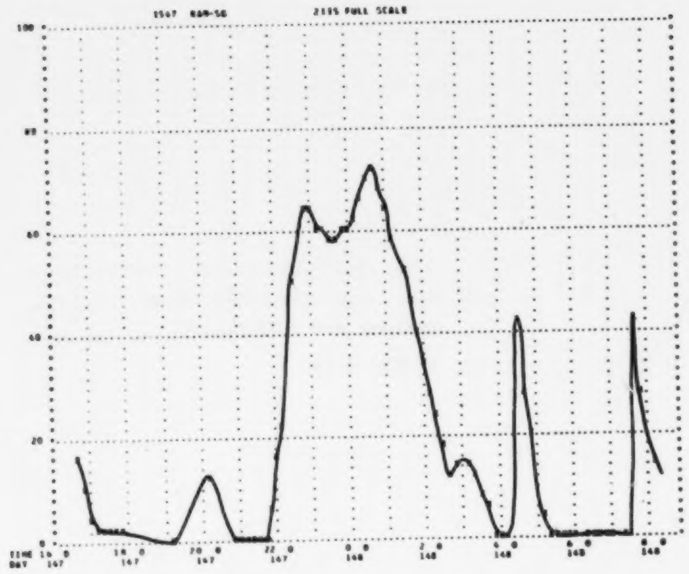
The re-inflation every third hour and the increased flow pressure against the 'Fabridam' can be seen in this plot.



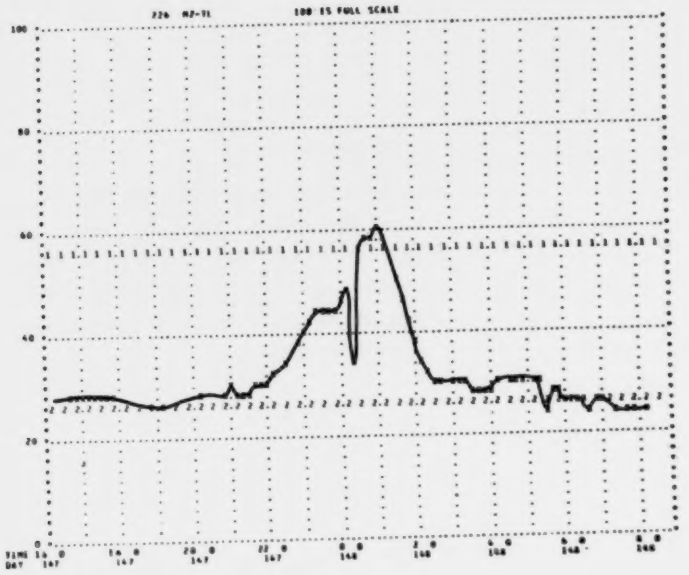
31st and Randolph

Runoff would have caused overflow for the duration of the rainfall event prior to modification. The pipe height is 102 inches.



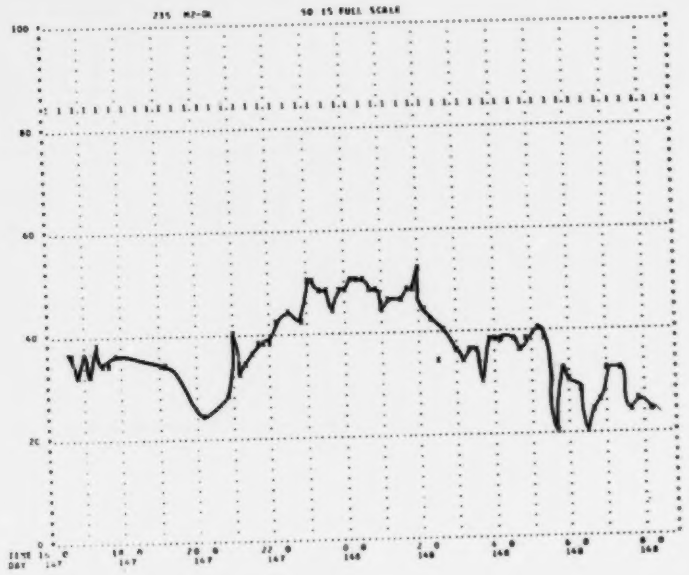


The plot shows re-inflation every third hour and the result of flow pressure on the 'Fabridam'. There was a rapid leak at this location which is shown in this plot.

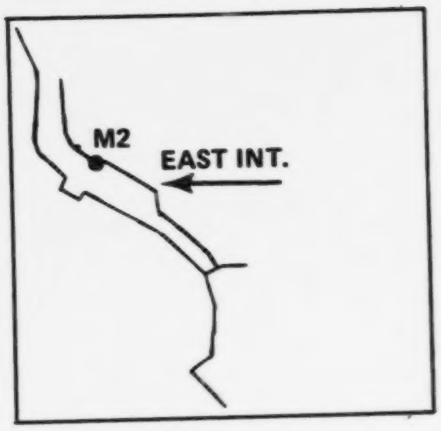


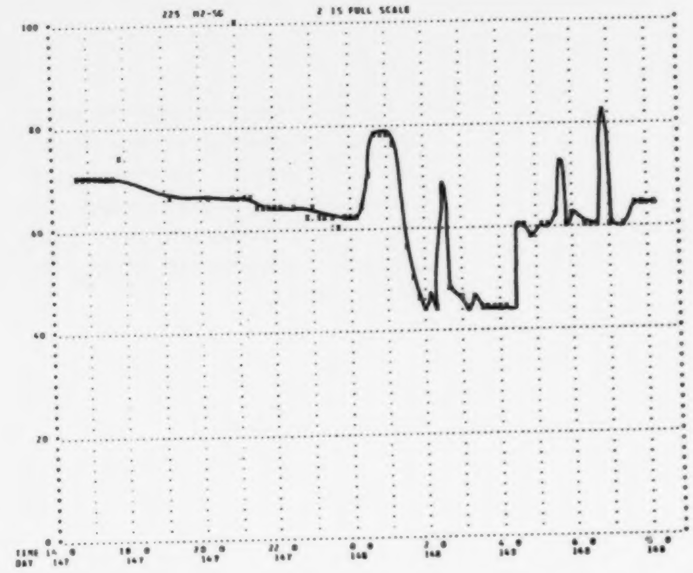
2nd and Main

This is a "Master Regulator" for the Minneapolis East Interceptor. Overflow would have occurred for at least 4 hours prior to modification at this regulator. Flow did exceed the height of the 'Fabridam' for approximately 45 minutes. The pipe height is 84 inches.

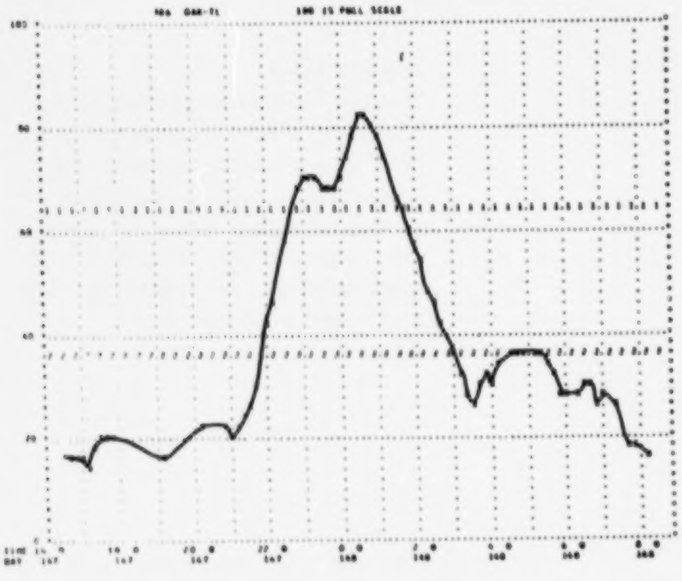


The trend of increased flow is shown in the interceptor downstream from this regulator. The pipe size is 42 inches.





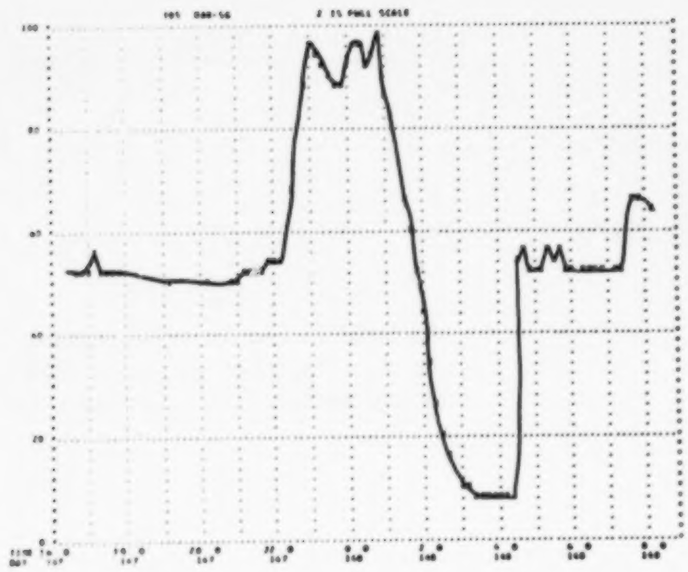
Re-inflation and increased pressure on the 'Fabridam' is shown. The loss of pressure is very slow here.



Oak Street

Runoff flow exceeded the height of the 'Fabridam' here for approximately 3 hours. (The old weir would have overflowed for over five hours and much more volume would have been lost.)

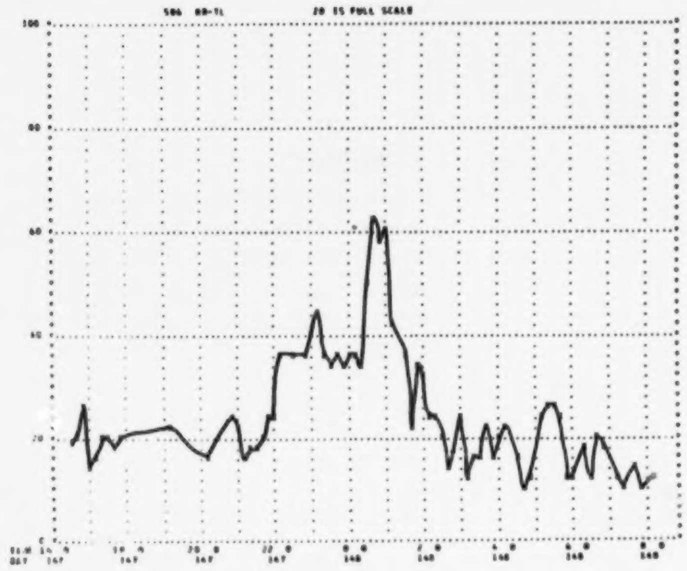
EAST INT.
OAK



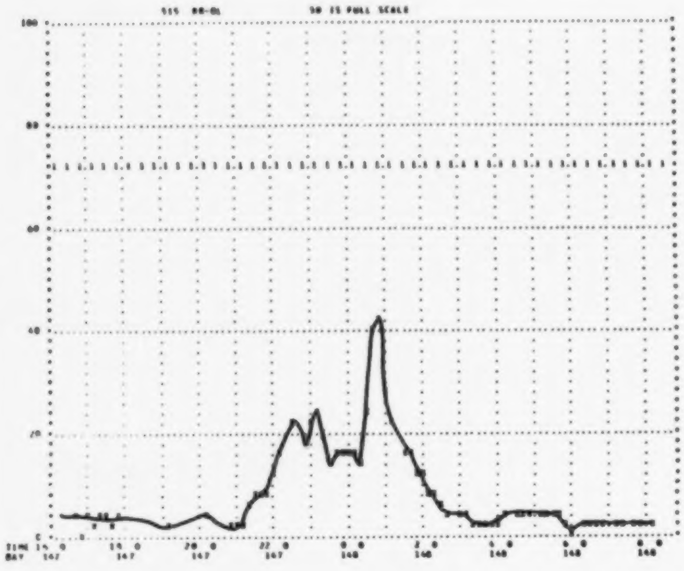
Increased pressure due to the storm flow and deflation of the 'Fabridam' is shown in this plot. Normally this dam is almost leak free, but the pressure relief valve apparently released air during the runoff event.

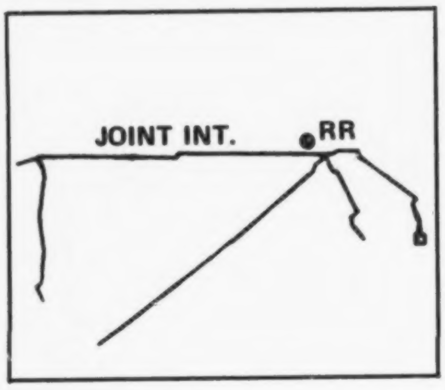
Rice and Rondo

The pattern of increased runoff is apparent in this plot. Because of high velocities, this data may not be correct. The pipe height is 114 inches.

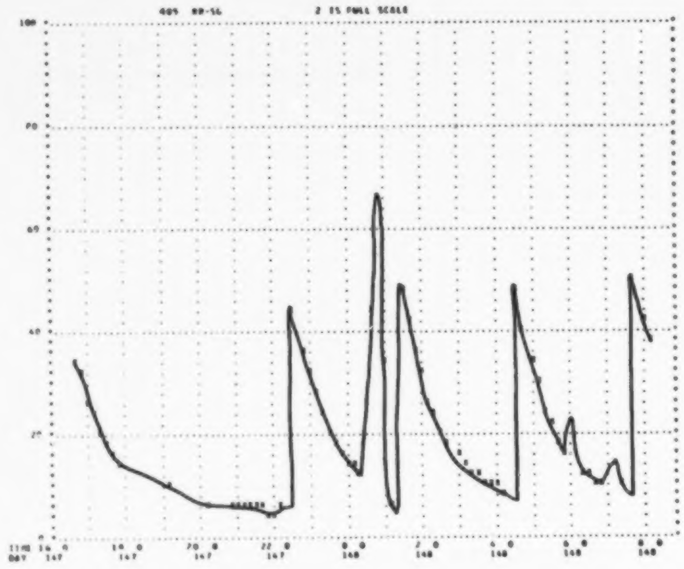


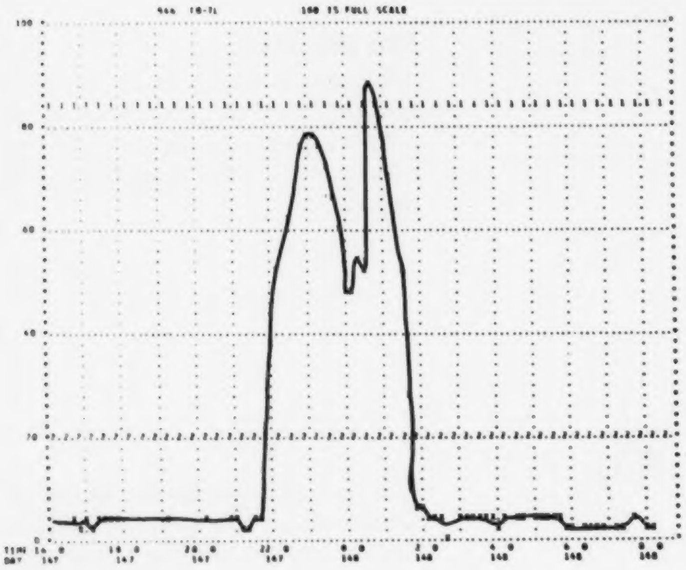
This plot of the level in the outlet section shows the effect of rainfall runoff. The dry weather outlet pipe size is 36".





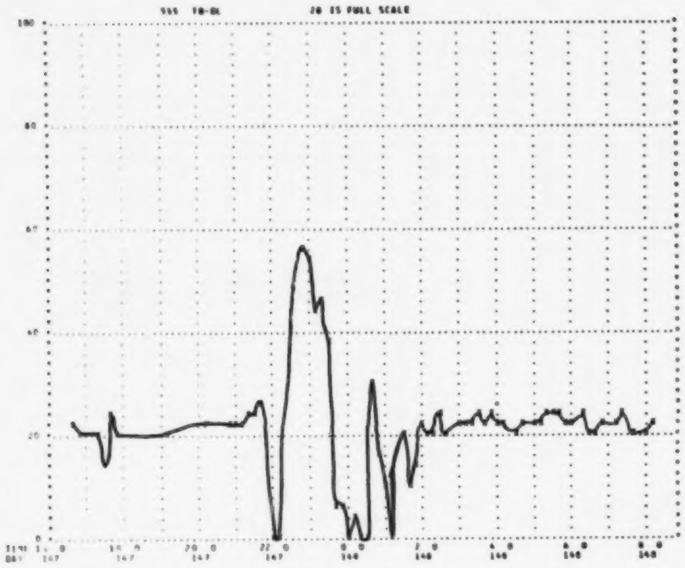
Increased pressure from runoff flow and re-inflation every third hour is shown here. This dam has a known leak and rapid loss of pressure.



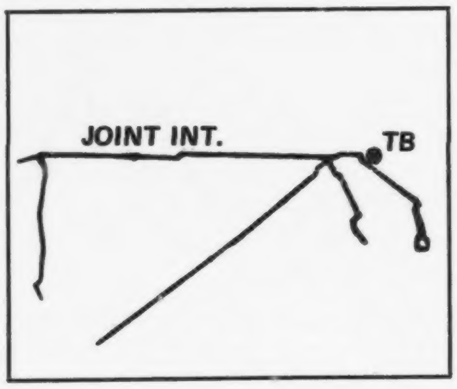


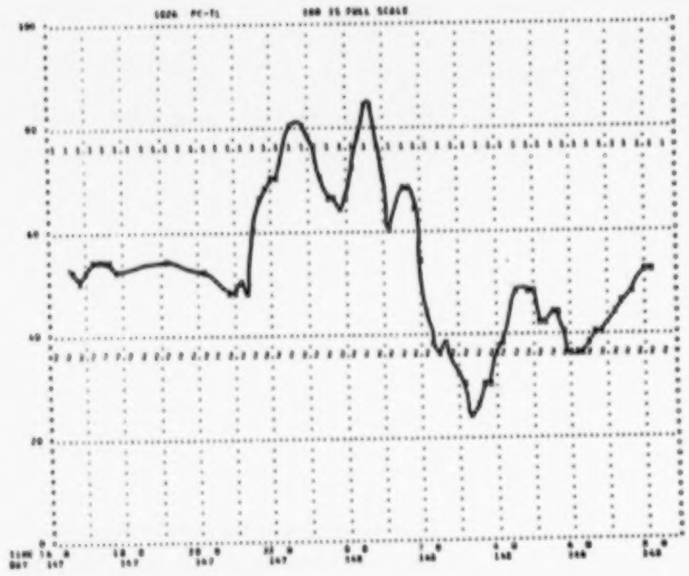
Trout Brook

Overflow occurred here for approximately 15 minutes. Prior to 'Fabridam' installation, this regulator would have overflowed almost 4 hours. The pipe height is 126 inches.



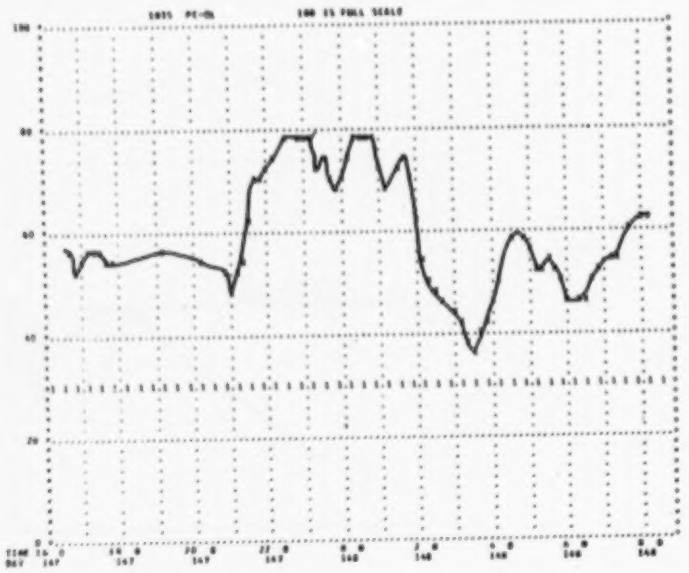
This data indicated a problem with the bubbler element which was later repaired.



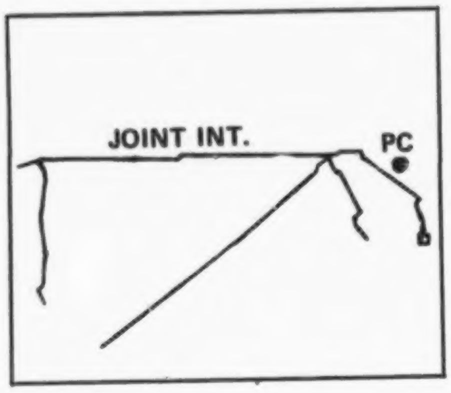


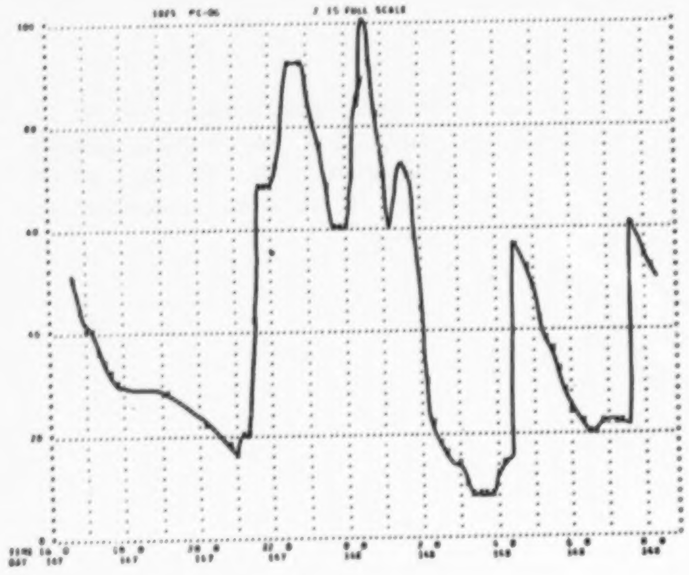
Phalen Creek

Runoff flow exceeded the height of the 'Fabridam' for a total of 1.25 hours. Dry weather flow would have been occurring before the event prior to modification. Pipe height is 112 inches.



A submerged entrance condition occurred continuously before, during, and after the rainfall event. Deficient outlet capacity is apparent. The pipe height is 30 inches.

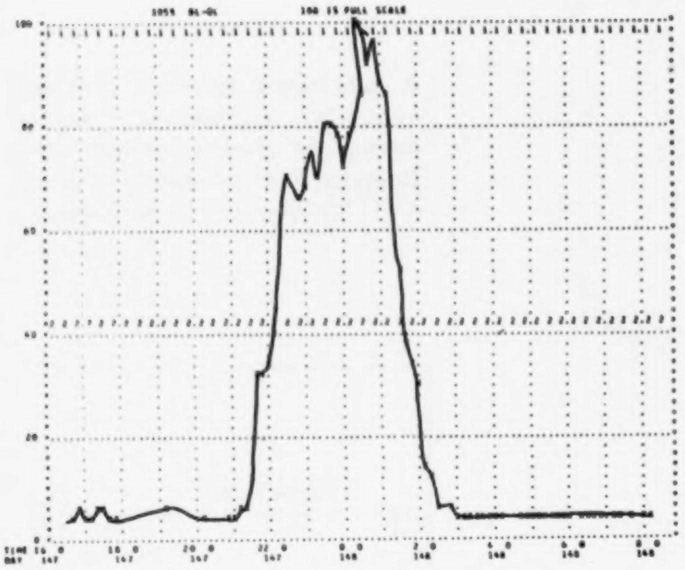




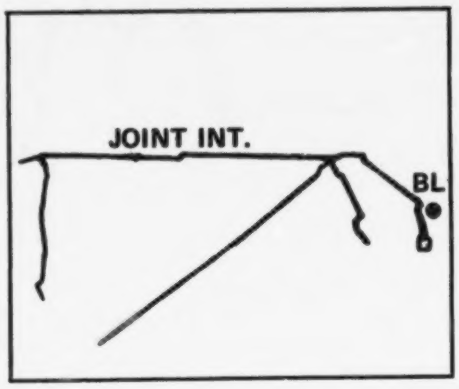
The increased pressure of additional flow and the re-inflation of the 'Fabridam' is shown in this plot.

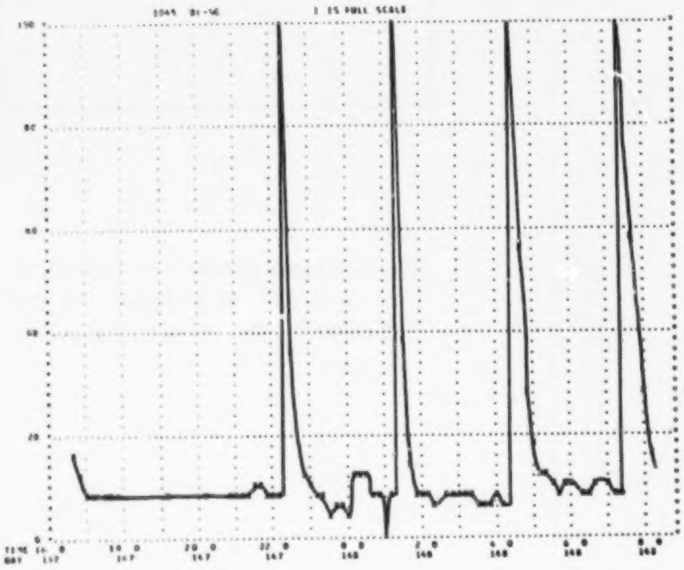
Belt Line

Because of high velocities, trunk sewer level data was not reliable.

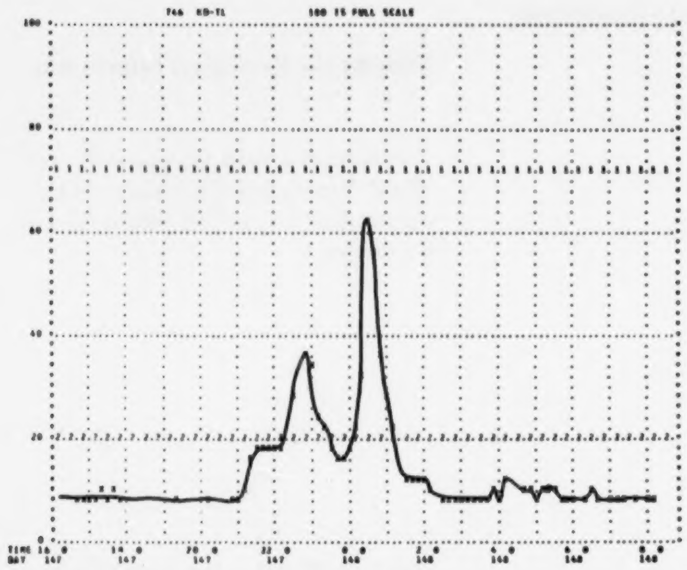


This level is in the outlet chamber. The entrance to the 24 inch outlet pipe was submerged for 3½ hours.



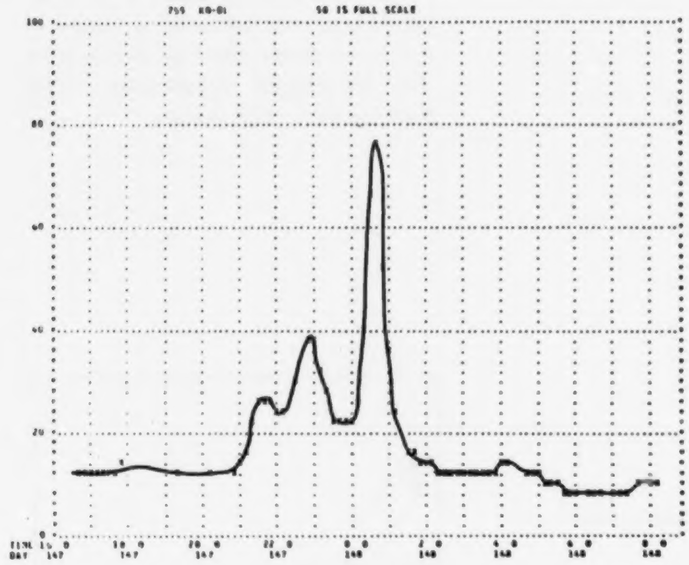


A very rapid pressure loss is evident. An air leak in the attachment caused this. The function of the dam is therefore somewhat uncertain.

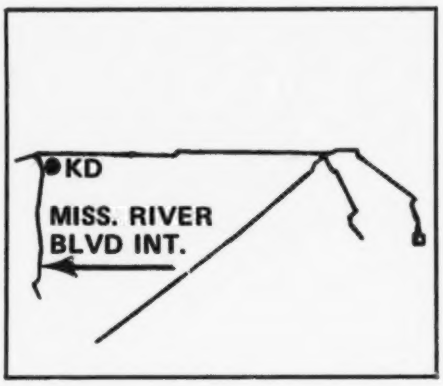


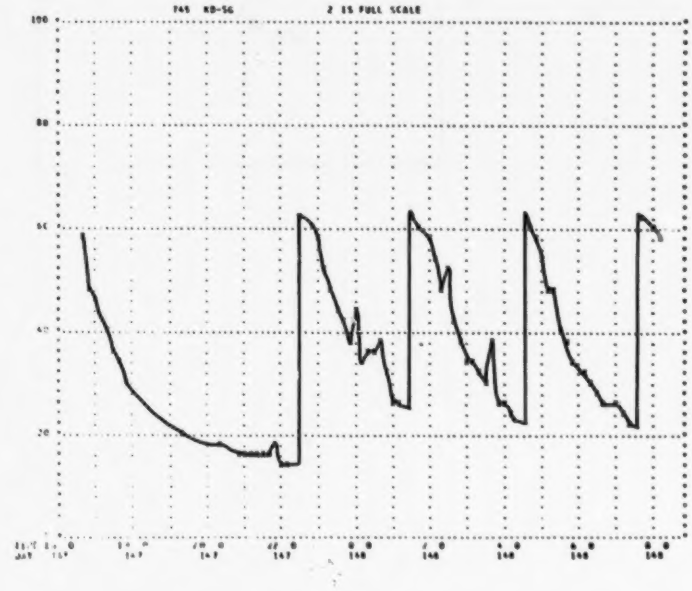
Kittsondale

Overflow would have occurred for a total of 2.25 hours at this regulator prior to modification. No flow passed over the inflated dam. Pipe height is 108 inches.



Increased flow in the outlet section is shown in this plot.

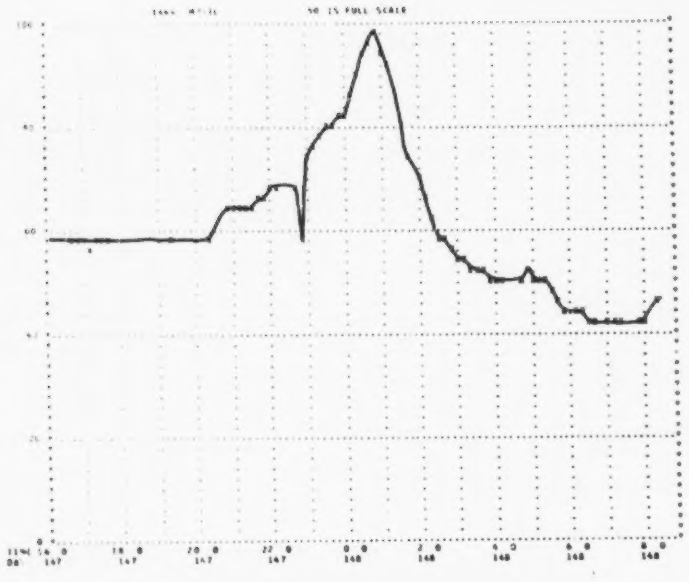




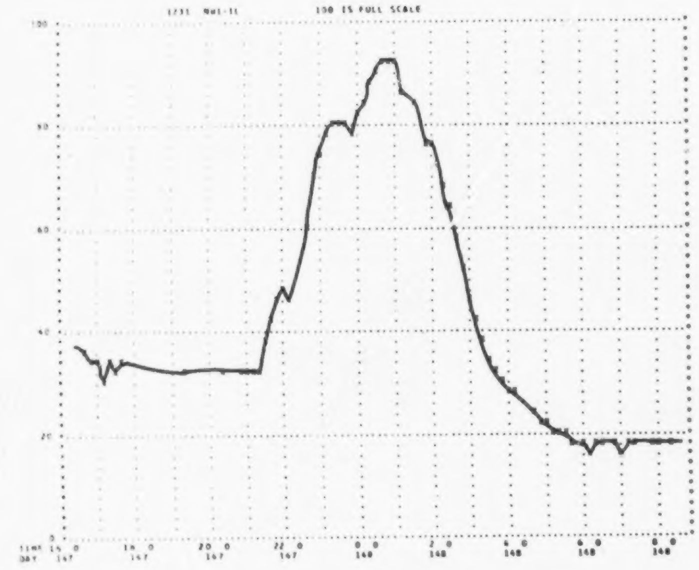
Inflation pressure adjustment every third hour is shown in this plot.

INTERCEPTORS

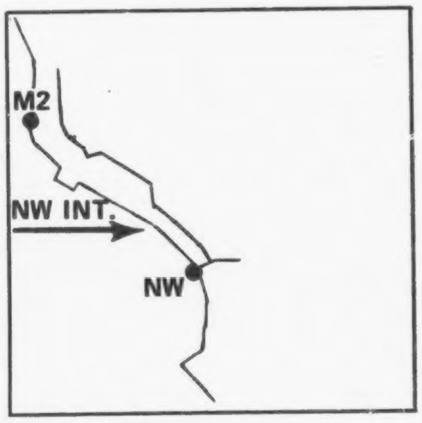
Minneapolis Northwest Interceptor



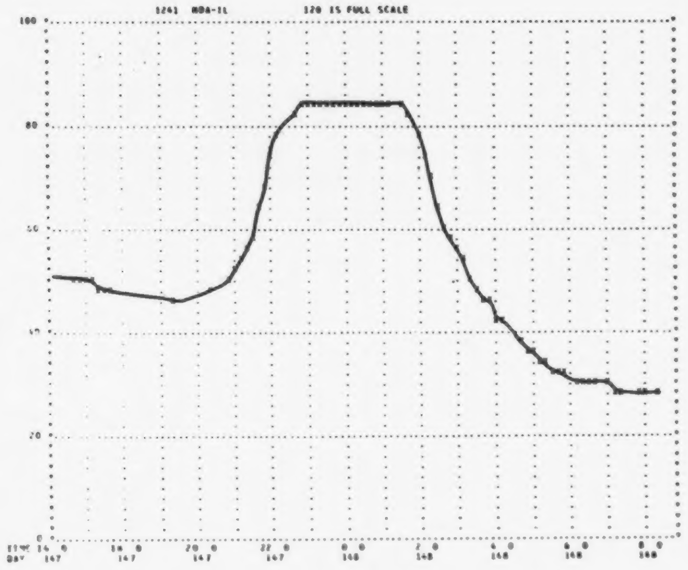
The rainfall almost filled the Minneapolis Northwest Interceptor at this location at 1 a.m. The pipe height is 54 inches.



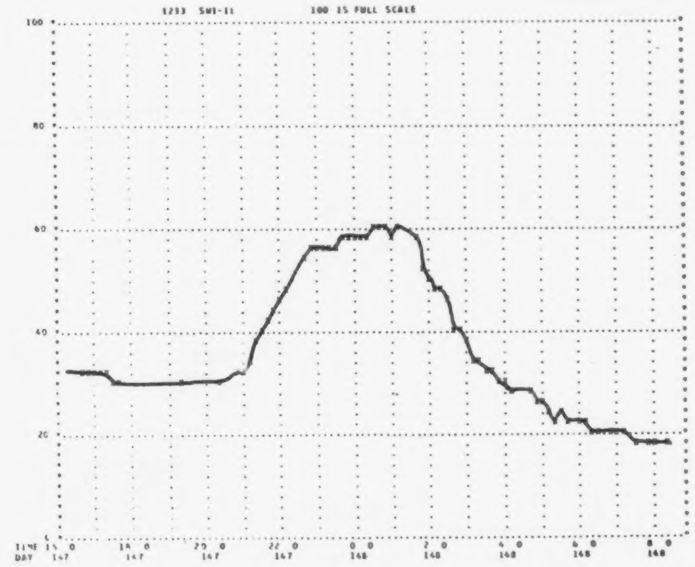
The runoff from the rainfall event in the northwest area of Minneapolis that was captured is shown in the interceptor level at the end of the Northwest interceptor. The pipe height is 123 inches.



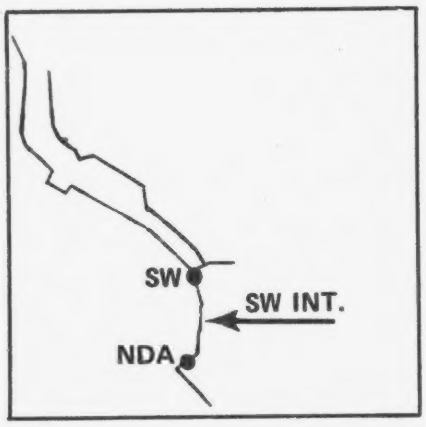
Minneapolis Southwest Interceptor

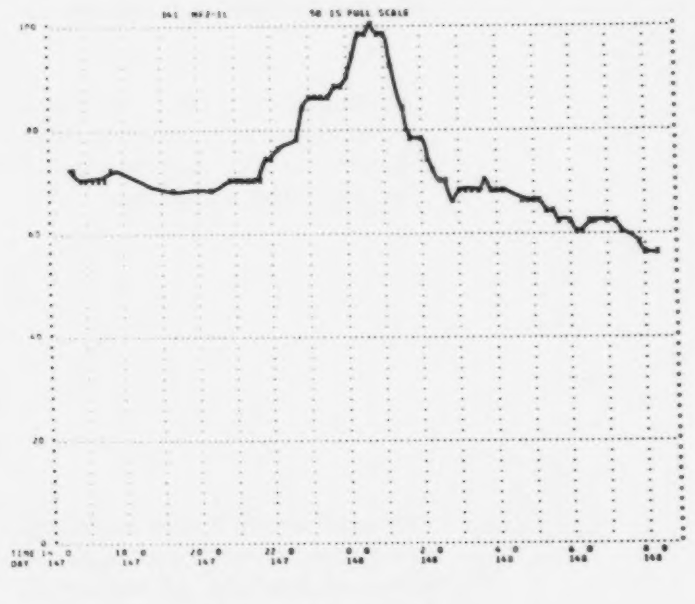


Increased runoff filled the Minneapolis Southwest Interceptor at this location for well over two hours. The pipe height is 72 inches.



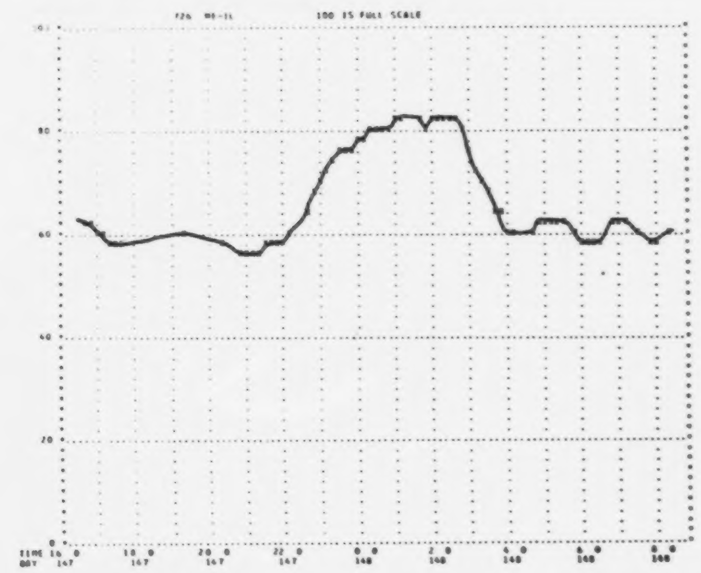
Increased runoff flow in the Minneapolis Southwest Interceptor is shown in this plot of level at its end. The pipe height is 72 inches.



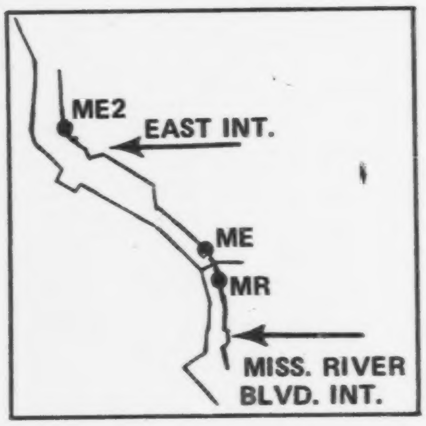


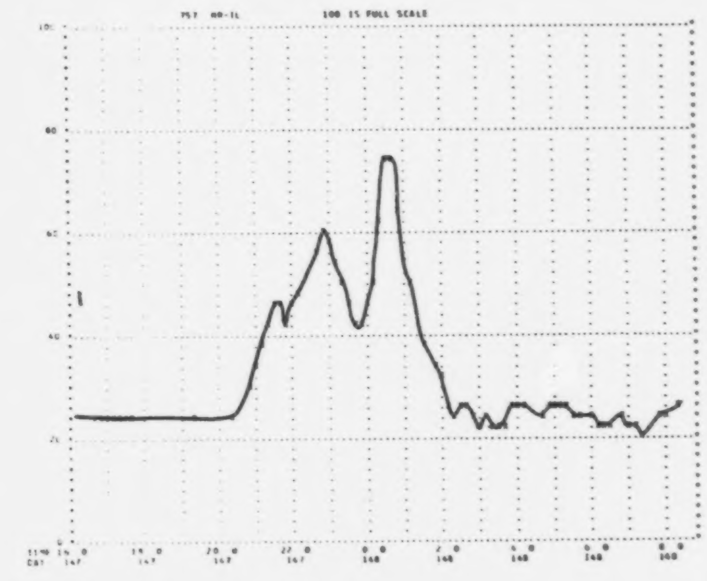
Minneapolis East Interceptor

The plot of level in the Minneapolis East Interceptor at Tenth and Marshall shows the effect of increased rainfall. The pipe height is 88 inches.



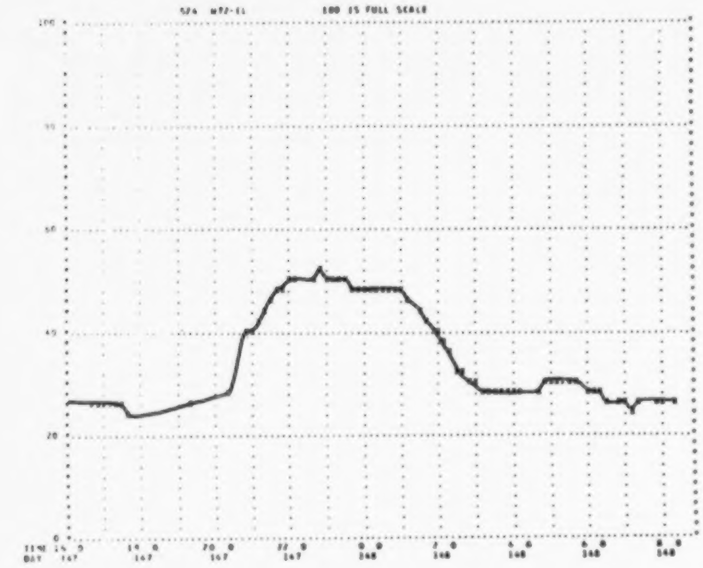
The effect of rainfall runoff on the flow in the Minneapolis East Interceptor is shown in this plot of level at its end. The pipe height is 72 inches.

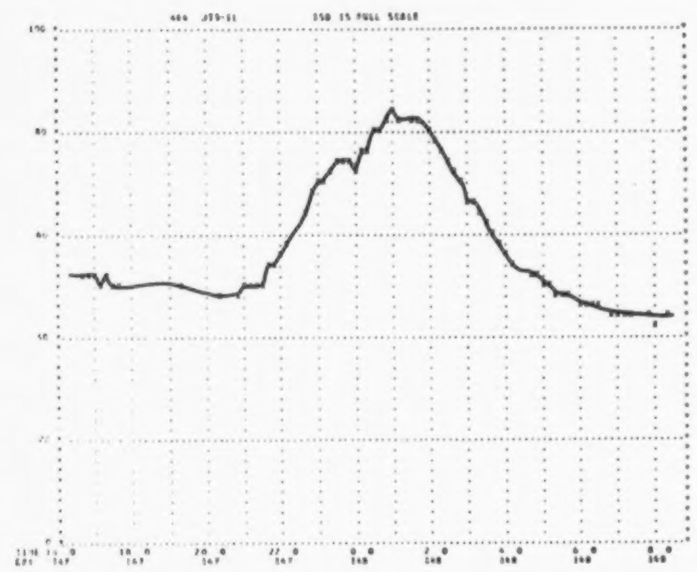




St. Paul Mississippi River Blvd. Interceptor

The St. Paul Mississippi River Blvd. Interceptor was filled to capacity around midnight due to the increased runoff. The pipe height is 70 inches.



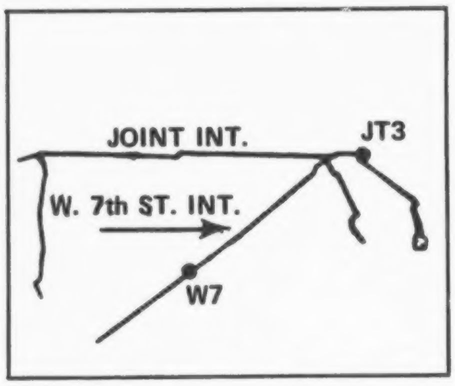


St. Paul W. 7th St. Interceptor

The level in St. Paul West Seventh St. Interceptor shows the increased flow during this runoff event. The pipe height is 70 inches.

Joint Interceptor

Runoff flow at the Joint Interceptor at Pine and Spruce reached almost 130 inches. The pipe height is 157 inches.



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APPENDIX B

Selected Project Materials

a. Tables of Inputs to Interceptors

Several tables of data abstracted from that accumulated during the sewer sampling and analytical phase of the program are presented to show examples of preliminary analysis of this information. Only average values are incorporated into the tables. Part C of this appendix illustrates what the average value obscures.

b. Figures of Inputs to Interceptors

Information of the type included in the tables has been applied to a schematic of the interceptor system to more graphically illustrate the sources of sewage load under average conditions.

c. Three-Dimensional Plots

The best way to illustrate the diurnal and day to day variations in wastewater flow or composition without resorting to statistical parameters was found to be graphical. These are photographs of three-dimensional models constructed by student-employees.

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HOURLY CONCENTRATIONS OF CHEMICAL OXYGEN DEMAND

In sewers
Tributary to the following:

				CHEMICAL OXYGEN DEMAND MG/L		
	STATION	SAMPLE PERIOD	NUMBER OF SAMPLES	MAX.	MIN.	MEAN
I	**Minneapolis Northwest Interceptor**					
	Camden	April, 1968–October, 1968	1005	1340	173	344
	Portland and Washington	July, 1967–January, 1968	262	1790	211	673
	Northwest Meter	October, 1966–July, 1967	651	1700	150	578
II	**Minneapolis Southwest Interceptor**					
	39th and Minnehaha	January, 1967–January, 1968	612	1630	181	426
	38th and Edmund	January, 1967–January, 1968	741	1920	183	574
	Southwest Meter	October, 1966–July, 1967	629	1420	174	466
III	**Minneapolis East Interceptor**					
	31st-Randolph	April, 1968–October, 1968	811	1990	184	593
	Second-Main	October, 1967–October, 1968	1059	1980	177	606
	Oak Street	April, 1968–October, 1968	967	1910	169	408
	East Meter	October, 1966–July, 1967	678	1910	168	622
IV	**Joint Interceptor**					
	Eustis	January, 1968–July, 1968	864	1950	187	625
	Wabash-Cromwell	January, 1968–April, 1968	24	1910	504	1132
	Kittsondale	April, 1968–July, 1968	351	1950	186	613
	Rice and Rondo	January, 1967–October, 1967	654	1940	227	890
	West Seventh Street	April, 1967–October, 1967	632	1870	178	479
	St. Peter and Kellogg	January, 1968–July, 1968	853	1810	179	523
	Trout Brook	January, 1967–October, 1967	723	1240	179	367
	Phalen Creek	January, 1968–July, 1968	981	1940	187	533
	Belt Line	January, 1967–January, 1968	570	1660	180	402
V	**Treatment Plant**					
	Plant Raw Waste	October, 1966–January, 1969	4719	1930	148	600
	Plant Primary Effluent	April, 1968–July, 1968	501	1310	181	405

NOTE: Data contains wet weather as well as dry weather flows.

AVERAGE INPUTS OF CHEMICAL OXYGEN DEMAND FROM KEY REGULATORS TO INTERCEPTORS

				AVERAGE CHEMICAL OXYGEN DEMAND	
	STATION	SAMPLE PERIOD	AVERAGE FLOW, MGD	MG/L	LB/DAY
I	**Minneapolis Northwest Interceptor**				
	Camden	May–August, 1968	10.5	345	30,000
	Portland–Washington	August–October, 1967	35	675	197,000
	Seabury	January, 1967–August-October, 1967	12	500	5,000
	Northwest Meter	November, 1966–May, 1967	50	580	242,000
II	**Minneapolis Southwest Interceptor**				
	39th-Minnehaha	January, 1967/August-October, 1967	8	430	29,000
	38th-Edmund	January, 1967/August-October, 1967	13.5	575	65,000
	Southwest Interceptor	November, 1966–May, 1967	37	470	145,000
III	**Minneapolis East Interceptor**				
	Randolph	May–August, 1968	14	595	69,000
	2nd-Main	May–August, 1968	27	605	136,000
	Oak	April–July, 1968	8	410	27,000
	East Meter	November, 1966–May, 1967	37	625	193,000
IV	**Mississippi River Boulevard Interceptor**				
	Otis	April–May, 1968	3.5	613	18,000
	Mississippi River Blvd.		11		
V	**Joint Interceptor**				
	Eustis	March–May, 1968	15	625	78,000
	Rice-Rondo	January–August, 1967	6	890	44,000
	W. 7th Interceptor	May–August, 1967	5	480	20,000
	St. Peter-Kellogg	March–May, 1968	0.8	525	4,000
	Trout Brook	January–August, 1967	11.5	370	35,000
	Phalen Creek	March–May, 1968	15	530	66,000
	Belt Line	January–August, 1967	9.3	400	31,000

NOTE: Hourly concentrations and flow depths are available.

PRELIMINARY ANALYSIS OF VOLUMETRIC AND COD LOAD INPUTS INTO THE MINNEAPOLIS–ST. PAUL INTERCEPTOR SYSTEM

Some flow data is estimated. COD concentration values are from Technicon AutoAnalyzer. COD concentrations in parentheses are calculated from differences in flow COD load.

		AVERAGE FLOW, MGD		AVERAGE COD MG/l.		AVERAGE COD # /DAY	
I	**Minneapolis Northwest Interceptor**						
	Camden	10.5		345		30,000	
	Other	24.5		(820)		167,000	
	Portland and Washington	35		675		197,000	
	Seabury	12		500		50,000	
	Other	3		(<0)		–5,000	
	TOTAL		50		580		242,000
II	**Minneapolis Southwest Interceptor**						
	39th-Minnehaha	8		430		29,000	
	38th-Edmund	13.5		575		65,000	
	Other	15.5		(395)		51,000	
	TOTAL		37		470		145,000
III	**Minneapolis East Interceptor**						
	Randolph	14		595		69,000	
	Other	13		(620)		67,000	
	Second and Main	27		605		136,000	
	Oak Street	8		410		27,000	
	Other	2		(1800)		30,000	
	TOTAL		37		625		193,000
IV	**Mississippi River Blvd. Interceptor**						
	Otis and Marshall	3.5		613		18,000	
	Other	7.5		(1150)		72,000	
	TOTAL		11		981		90,000
V	**Joint Interceptor**						
	Eustis	15		625		78,000	
	Rice and Rondo	6		890		44,000	
	West Seventh	5		480		20,000	
	St. Peter and Kellogg	0.8		525		4,000	
	Trout Brook	11.5		370		35,000	
	Phalen Creek	15		530		66,000	
	Belt Line	9.3		400		31,000	
	Other	7.4		(1250)		77,000	
	TOTAL		70.0		608		355,000
	Plant						
	TOTAL		205		600		1,025,000

AVERAGE INPUTS OF CHLORIDES FROM KEY REGULATORS TO INTERCEPTORS

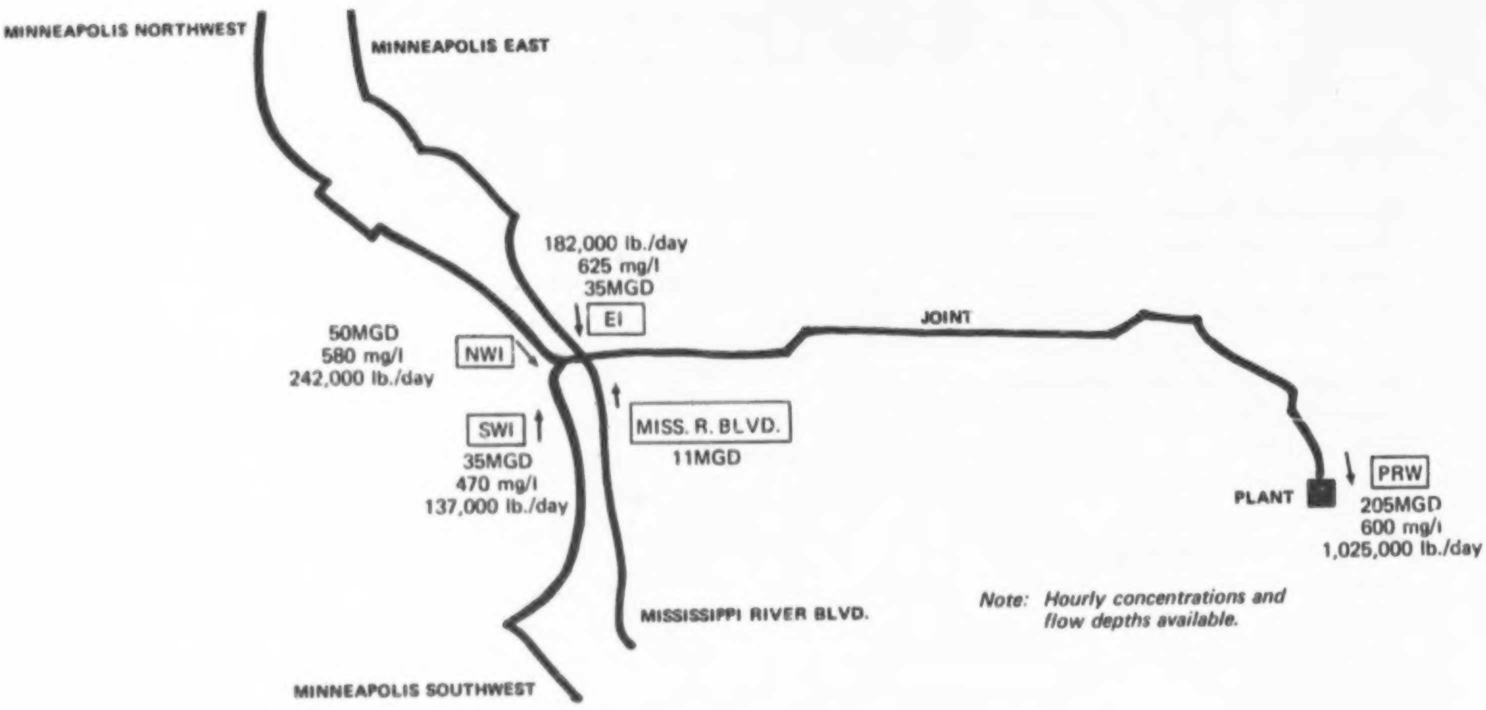
	STATION	SAMPLE PERIOD	AVERAGE FLOW, MGD	AVERAGE CHLORIDES, MG/L	LB/DAY
I	**Minneapolis Northwest Interceptor**				
	Portland-Washington	August – October, 1967	35	170	50,000
	Seabury	January, 1967–August-October, 1967	12	80	8,000
	Northwest Meter	November, 1966–May, 1967	50	165	69,000
II	**Minneapolis Southwest Interceptor**				
	39th-Minnehaha	January, 1967/August-October, 1967	8	110	7,000
	38th-Edmund	January, 1967/August-October, 1967	13.5	180	20,000
	Southwest Interceptor	November, 1966–May, 1967	37	175	54,000
III	**Minneapolis East Interceptor**				
	East Meter	November, 1966–May, 1967	37	90	28,000
IV	**Joint Interceptor**				
	Rice-Rondo	January–August, 1967	6	110	6,000
	W. 7th Interceptor	May–August, 1967	5	65	3,000
	Trout Brook	January–August, 1967	11.5	90	9,000
	Belt Line	January–August, 1967	9.3	90	7,000

NOTE: Hourly concentrations and flow depths are available.

AVERAGE INPUTS OF AMMONIA NITROGEN FROM KEY REGULATORS TO INTERCEPTORS

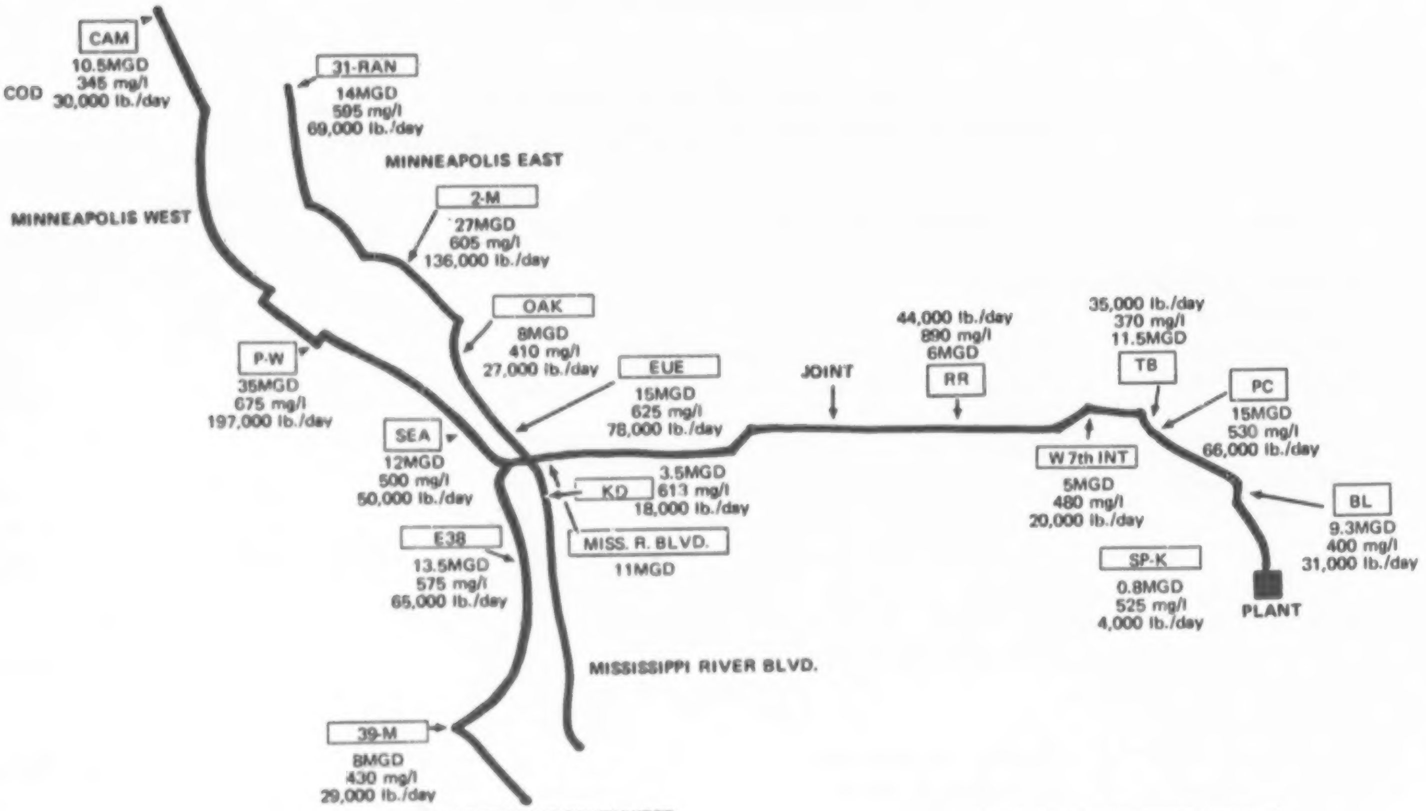
	STATION	SAMPLE PERIOD	AVERAGE FLOW, MGD	AVERAGE AMMONIA NITROGEN, MG/L	LB/DAY
I	**Minneapolis Northwest Interceptor**				
	Portland-Washington	August – October, 1967	35	15	4,400
	Seabury	January, 1967–August-October, 1967	12	8	800
	Northwest Meter	November, 1966–May, 1967	50	17	7,000
II	**Minneapolis Southwest Interceptor**				
	39th-Minnehaha	January, 1967/August-October, 1967	8	14	900
	38th-Edmund	January, 1967/August-October, 1967	13.5	16	1,800
	Southwest Interceptor	November, 1966–May, 1967	37	20.5	6,300
III	**Minneapolis East Interceptor**				
	East Meter	November, 1966–May, 1967	37	8	2,500
IV	**Joint Interceptor**				
	Rice-Rondo	January–August, 1967	6	21	1,100
	W. 7th Interceptor	May–August, 1967	5	4.5	200
	Trout Brook	January–August, 1967	11.5	11	1,100
	Belt Line	January–August, 1967	9.3	15	1,200

NOTE: Hourly concentrations and flow depths are available.


MINNEAPOLIS NORTHWEST
MINNEAPOLIS EAST
182,000 lb./day
625 mg/l
35MGD
EI
50MGD
580 mg/l
242,000 lb./day
NWI
JOINT
SWI
35MGD
470 mg/l
137,000 lb./day
MISS. R. BLVD.
11MGD
PRW
PLANT
205MGD
600 mg/l
1,025,000 lb./day
MISSISSIPPI RIVER BLVD.
MINNEAPOLIS SOUTHWEST

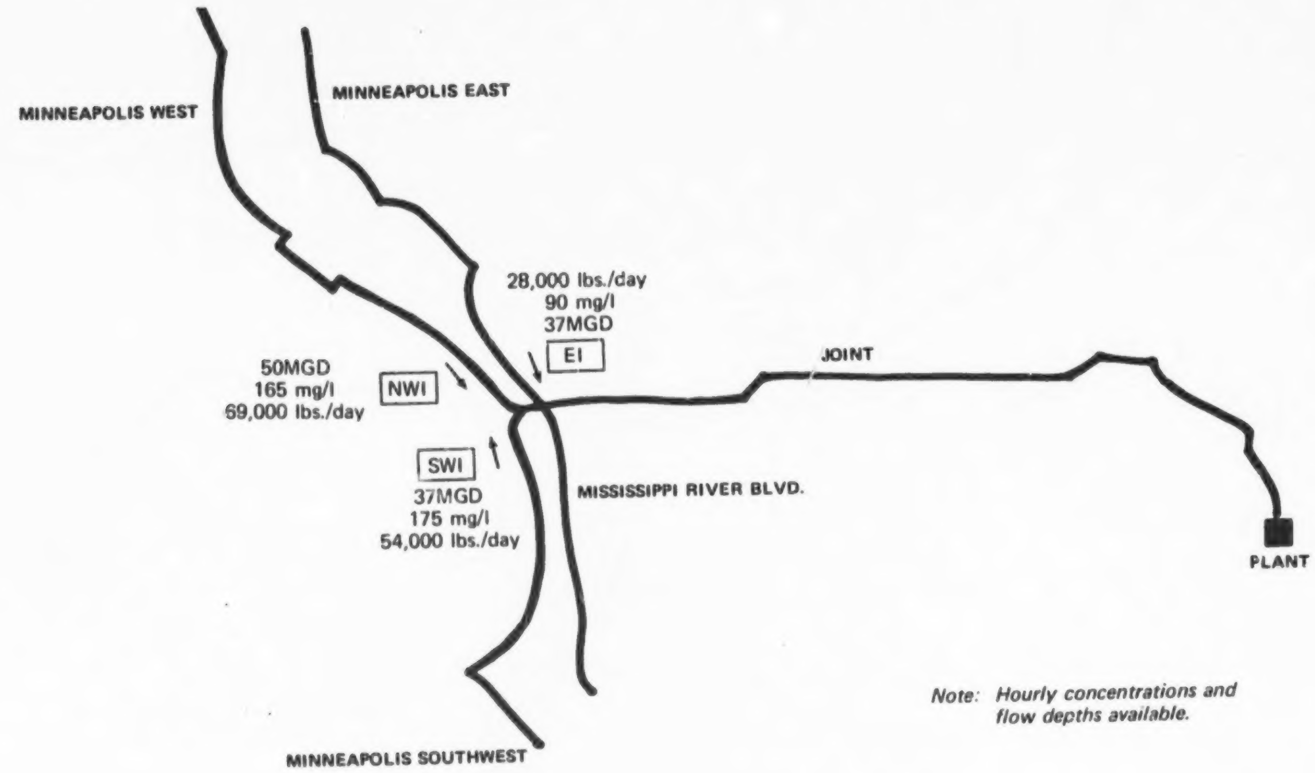
Note: Hourly concentrations and flow depths available.

Input of Chemical Oxygen Demand from Minneapolis Meters to Joint Interceptor under Average Conditions

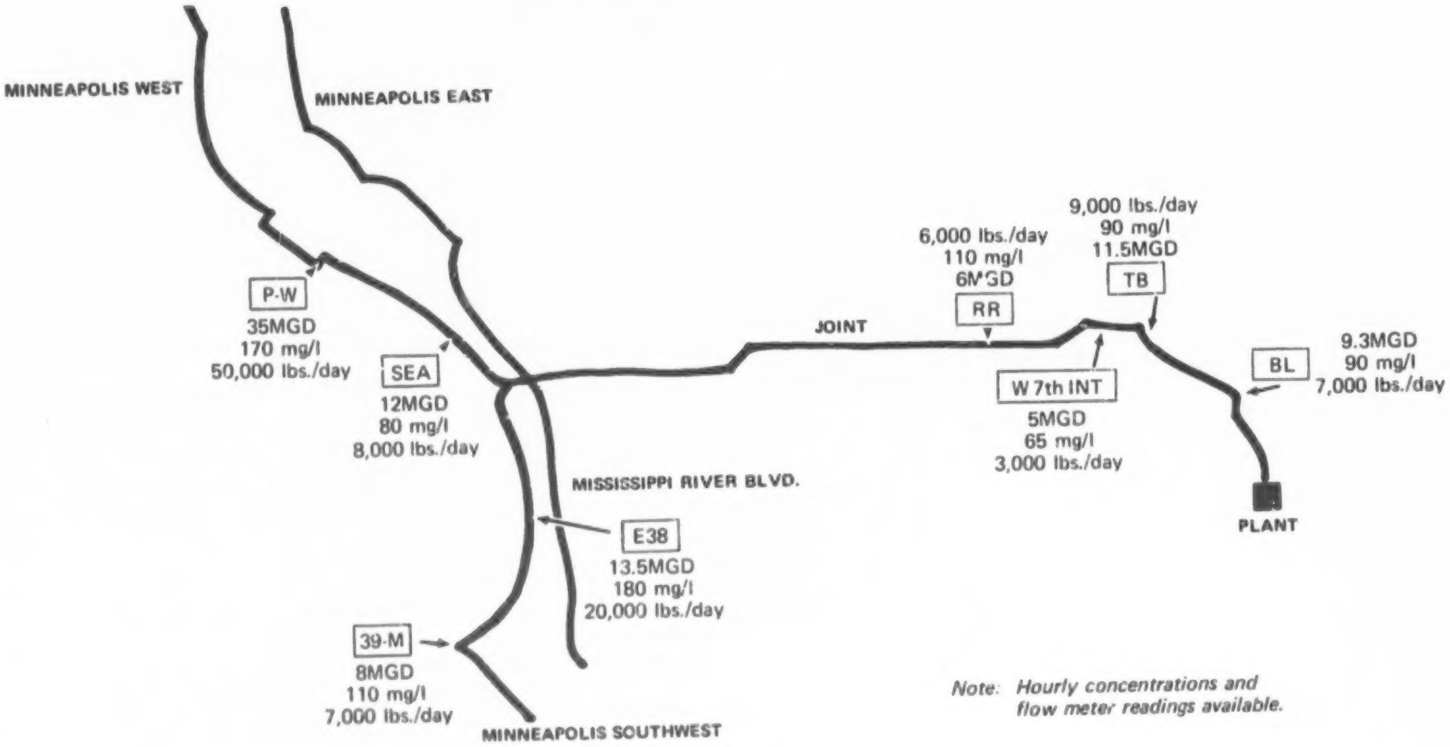

CAM
10.5MGD
345 mg/l
COD
30,000 lb./day
31-RAN
14MGD
595 mg/l
69,000 lb./day
MINNEAPOLIS EAST
MINNEAPOLIS WEST
2-M
27MGD
605 mg/l
136,000 lb./day
OAK
8MGD
410 mg/l
27,000 lb./day
P-W
35MGD
675 mg/l
197,000 lb./day
EUE
15MGD
625 mg/l
78,000 lb./day
JOINT
44,000 lb./day
890 mg/l
6MGD
RR
35,000 lb./day
370 mg/l
11.5MGD
TB
PC
15MGD
530 mg/l
66,000 lb./day
SEA
12MGD
500 mg/l
50,000 lb./day
KD
3.5MGD
613 mg/l
18,000 lb./day
MISS. R. BLVD.
11MGD
E38
13.5MGD
575 mg/l
65,000 lb./day
W 7th INT
5MGD
480 mg/l
20,000 lb./day
BL
9.3MGD
400 mg/l
31,000 lb./day
SP-K
0.8MGD
525 mg/l
4,000 lb./day
PLANT
MISSISSIPPI RIVER BLVD.
39-M
8MGD
430 mg/l
29,000 lb./day
MINNEAPOLIS SOUTHWEST

Note: Hourly concentrations and flow meter readings available.

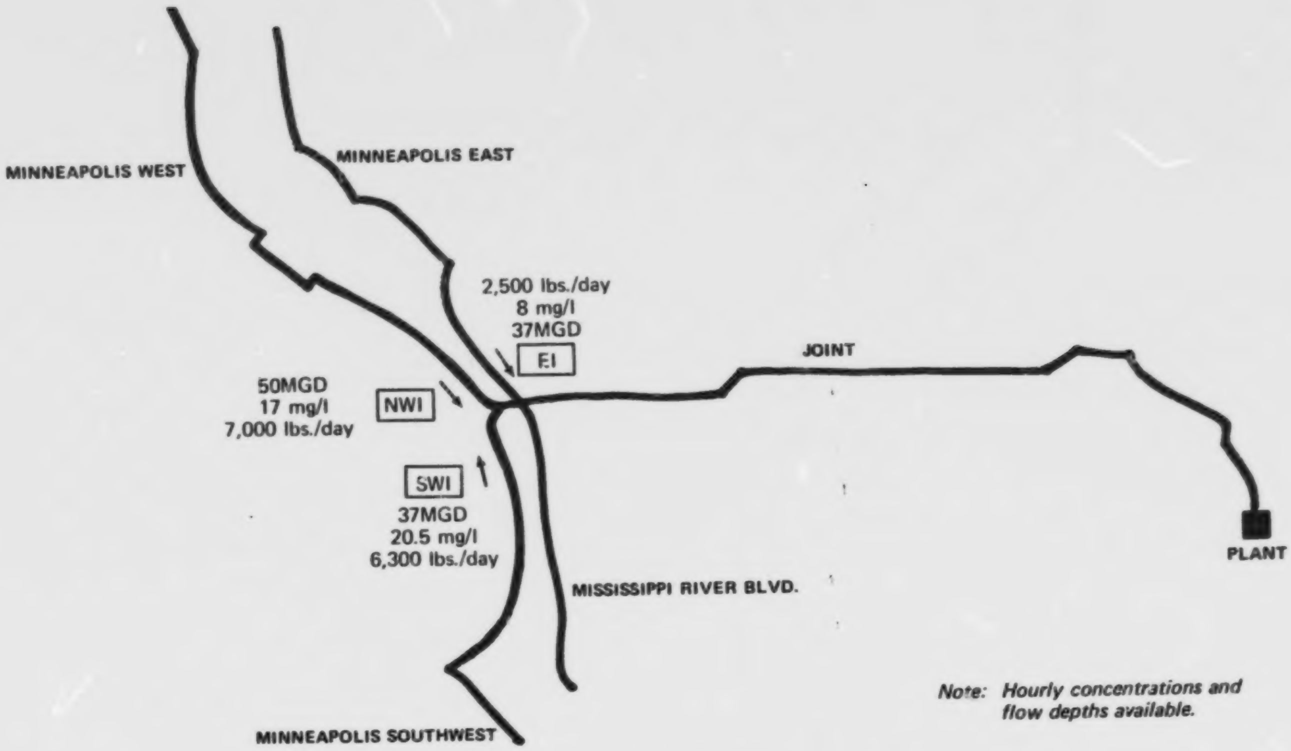
Input of Chemical Oxygen Demand from Major Regulators to Interceptors under Average Conditions


MINNEAPOLIS WEST
MINNEAPOLIS EAST
28,000 lbs./day
90 mg/l
37MGD
EI
50MGD
165 mg/l
69,000 lbs./day
NWI
JOINT
SWI
37MGD
175 mg/l
54,000 lbs./day
MISSISSIPPI RIVER BLVD.
PLANT
Note: Hourly concentrations and
flow depths available.
MINNEAPOLIS SOUTHWEST

Input of Chlorides from
Minneapolis Meters to Joint Interceptor
under Average Conditions

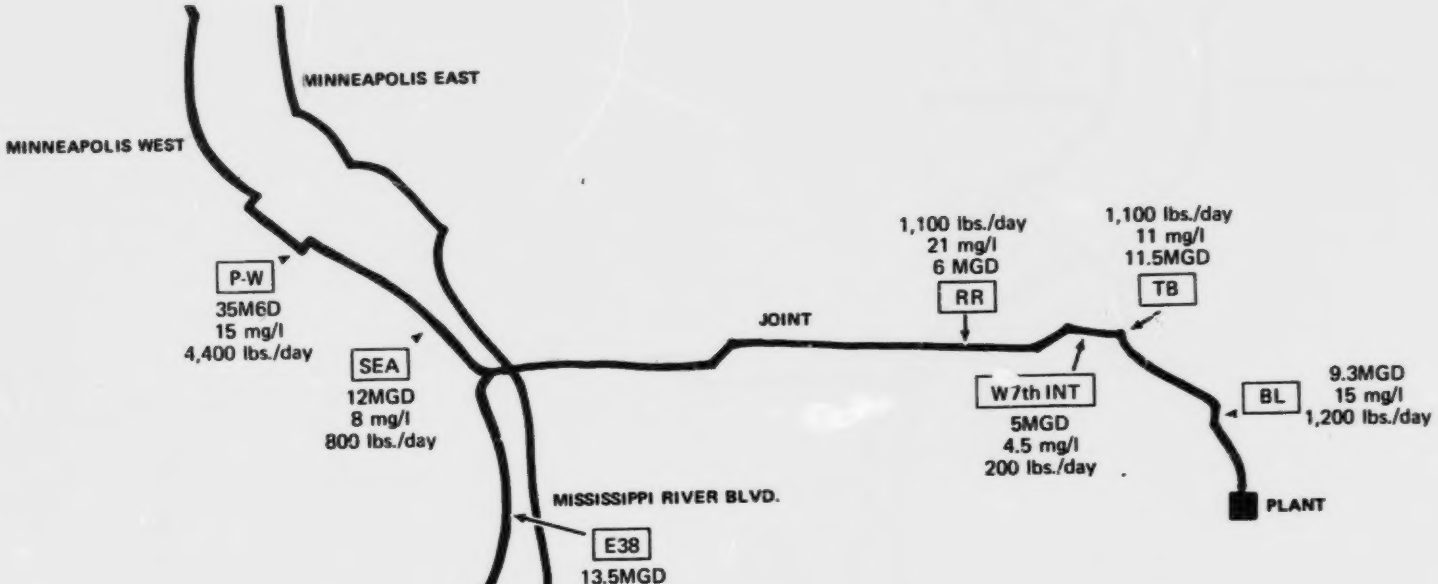

MINNEAPOLIS WEST
MINNEAPOLIS EAST
P-W
35MGD
170 mg/l
50,000 lbs./day
SEA
12MGD
80 mg/l
8,000 lbs./day
JOINT
6,000 lbs./day
110 mg/l
6MGD
RR
9,000 lbs./day
90 mg/l
11.5MGD
TB
W 7th INT
5MGD
65 mg/l
3,000 lbs./day
BL
9.3MGD
90 mg/l
7,000 lbs./day
MISSISSIPPI RIVER BLVD.
PLANT
E38
13.5MGD
180 mg/l
20,000 lbs./day
39-M
8MGD
110 mg/l
7,000 lbs./day
MINNEAPOLIS SOUTHWEST
Note: Hourly concentrations and
flow meter readings available.

Input of Chlorides from
Major Regulators to
Interceptors under Average Conditions


MINNEAPOLIS WEST
MINNEAPOLIS EAST
2,500 lbs./day
8 mg/l
37MGD
EI
JOINT
50MGD
17 mg/l
7,000 lbs./day
NWI
SWI
37MGD
20.5 mg/l
6,300 lbs./day
MISSISSIPPI RIVER BLVD.
PLANT
MINNEAPOLIS SOUTHWEST

Note: Hourly concentrations and flow depths available.

Input of Ammonia Nitrogen from Minneapolis Meters to Joint Interceptor under Average Conditions

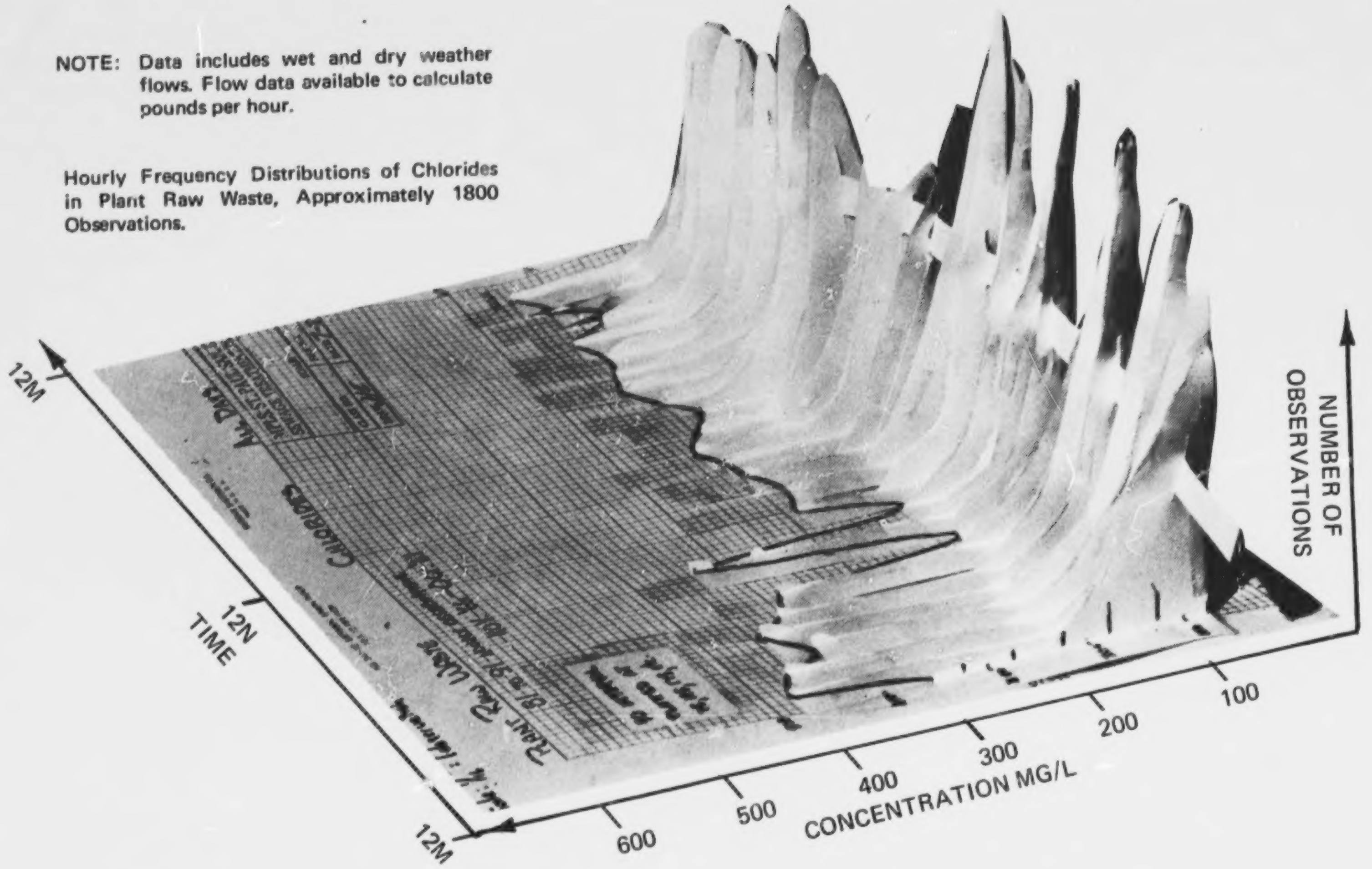

MINNEAPOLIS EAST
MINNEAPOLIS WEST
P-W
35M6D
15 mg/l
4,400 lbs./day
SEA
12MGD
8 mg/l
800 lbs./day
JOINT
1,100 lbs./day
21 mg/l
6 MGD
RR
1,100 lbs./day
11 mg/l
11.5MGD
TB
W7th INT
5MGD
4.5 mg/l
200 lbs./day
BL
9.3MGD
15 mg/l
1,200 lbs./day
PLANT
MISSISSIPPI RIVER BLVD.
E38
13.5MGD
16 mg/l
1,800 lbs./day
39-M
8MGD
14 mg/l
900 lbs./day
MINNEAPOLIS SOUTHWEST

Note: Hourly concentrations and flow depths available.

Input of Ammonia Nitrogen from Major Regulators to Interceptors under Average Conditions

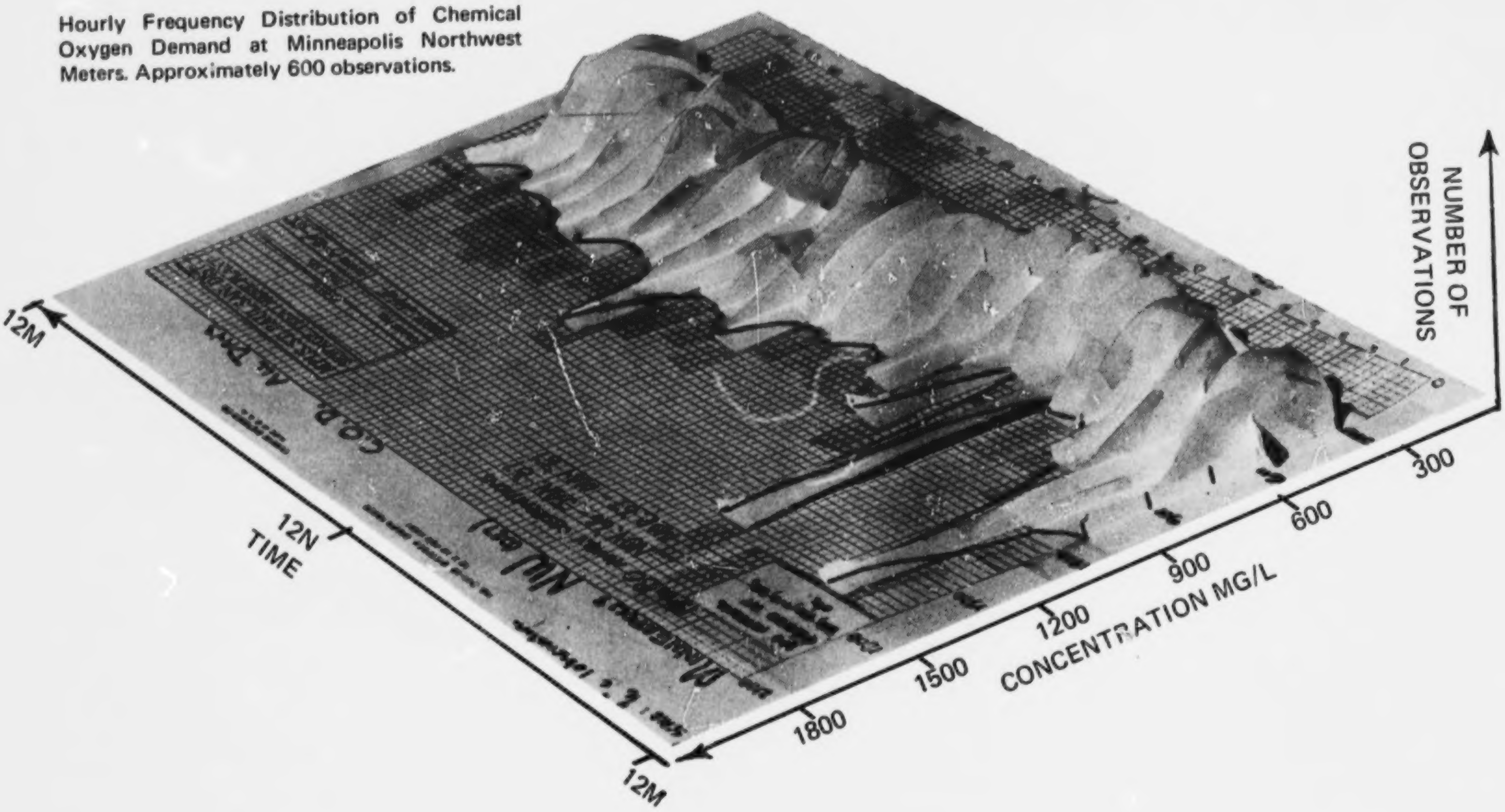
NOTE: Data includes wet and dry weather flows. Flow data available to calculate pounds per hour.

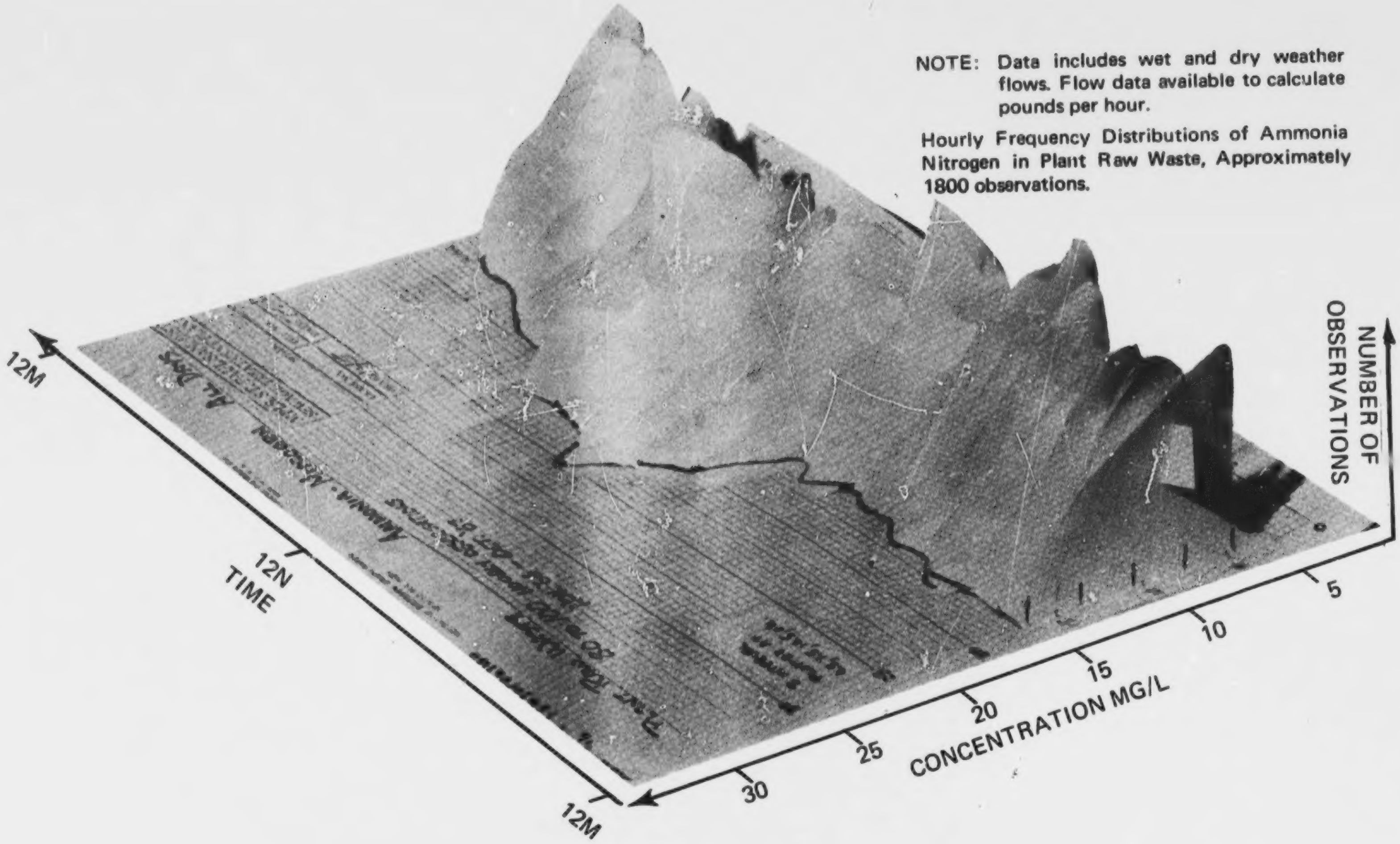
Hourly Frequency Distributions of Chlorides in Plant Raw Waste, Approximately 1800 Observations.



NOTE: Data includes wet and dry weather flows. Flow data available to calculate pounds per hour.

Hourly Frequency Distribution of Chemical Oxygen Demand at Minneapolis Northwest Meters. Approximately 600 observations.



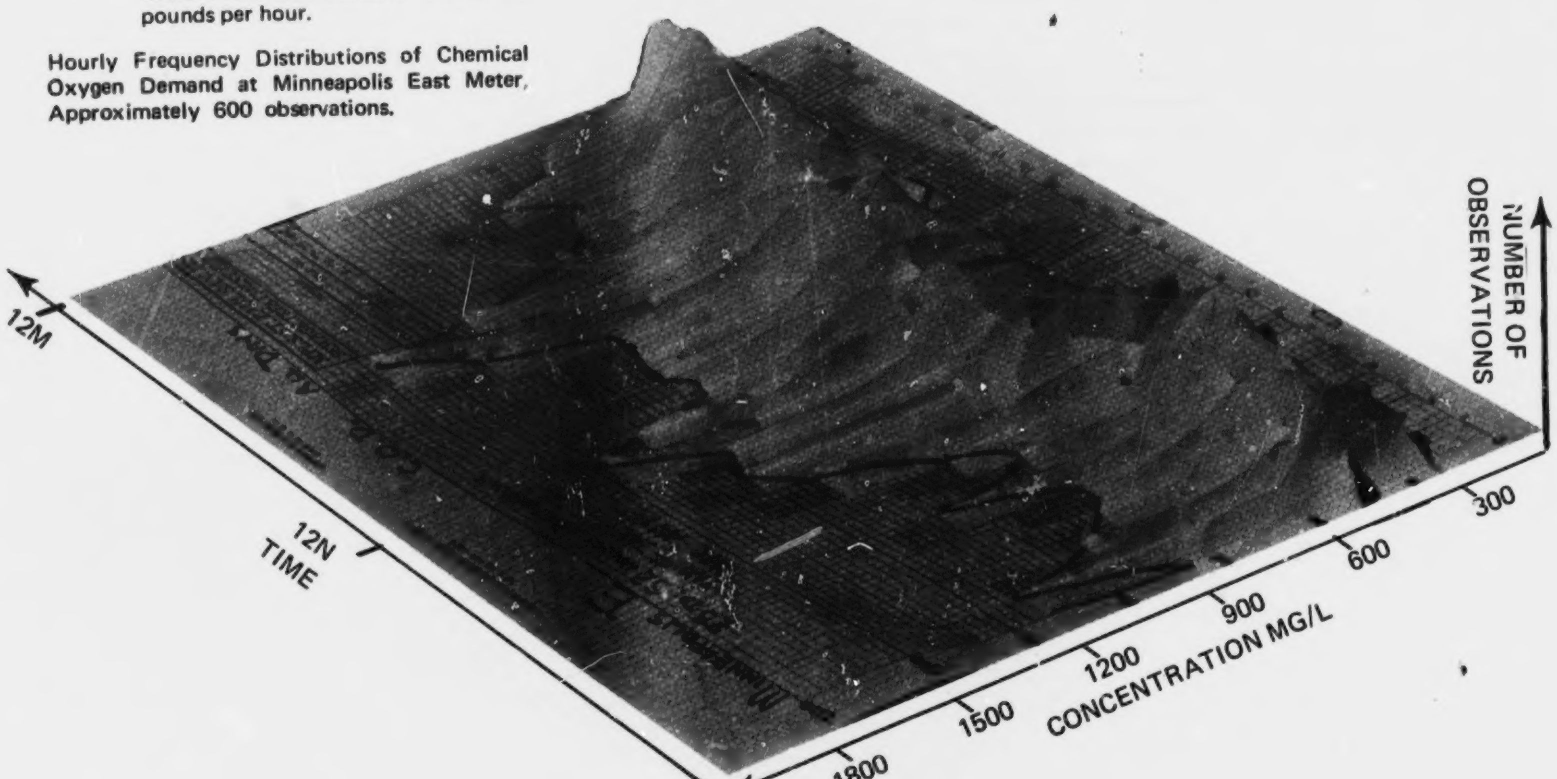


NOTE: Data includes wet and dry weather flows. Flow data available to calculate pounds per hour.

Hourly Frequency Distributions of Ammonia Nitrogen in Plant Raw Waste, Approximately 1800 observations.

NOTE: Data includes wet and dry weather flows. Flow data available to calculate pounds per hour.

Hourly Frequency Distributions of Chemical Oxygen Demand at Minneapolis East Meter, Approximately 600 observations.



Part II

MATHEMATICAL MODEL OF URBAN STORM RUNOFF AND THE INTERCEPTOR SEWER SYSTEM OF THE MINNEAPOLIS-ST. PAUL SANITARY DISTRICT

by
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and
The Federal Water Quality Administration

I. INTRODUCTION

The cities of Minneapolis and St. Paul are served by a combined sewer system which is designed to carry both normal dry-weather sanitary sewage and storm-water runoff. Originally the main trunk lines discharged the combined flow directly into the Mississippi River. However, in the 1930's interceptor sewers were constructed to collect the flow that would normally be discharged into the river and convey it to a treatment plant. Diversion structures were built into the trunk sewers to divert the flow into the new interceptor sewers. The interceptor sewers were designed to carry the normal dry-weather sanitary flow plus a small amount of storm-water runoff, but excess storm-water still had to be discharged into the river during large storms. Figure 1 shows the location of the interceptor sewers, the main diversion structures, and the inlets to the interceptor lines.

Originally most of the major diversion structures had fixed-height dams. Then in 1968 remotely-controlled fabridams and gates were installed at the diversion structures. These controllable gates and fabridams allow an operator to alter the system according to current conditions in the sewer system. With the variable-control diversion structures, advantage can be taken of the non-uniformity of rainfall distribution to obtain the maximum capture of runoff. Larger amounts of runoff can be directed into the sewer system at certain locations if it is known that little or no rain is occurring in other areas of the cities. However, it is difficult for an operator to make quantitative decisions about the amount of rainfall and storm runoff in the system. A mathematical model of the Minneapolis-St. Paul interceptor sewer system [1]* was therefore developed to aid the operators in determining the expected flow at critical points in the system so that gates and fabridams could be manipulated to retain the maximum flow in the system and release the least overflow to the Mississippi River.

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*Numbers in brackets refer to references.

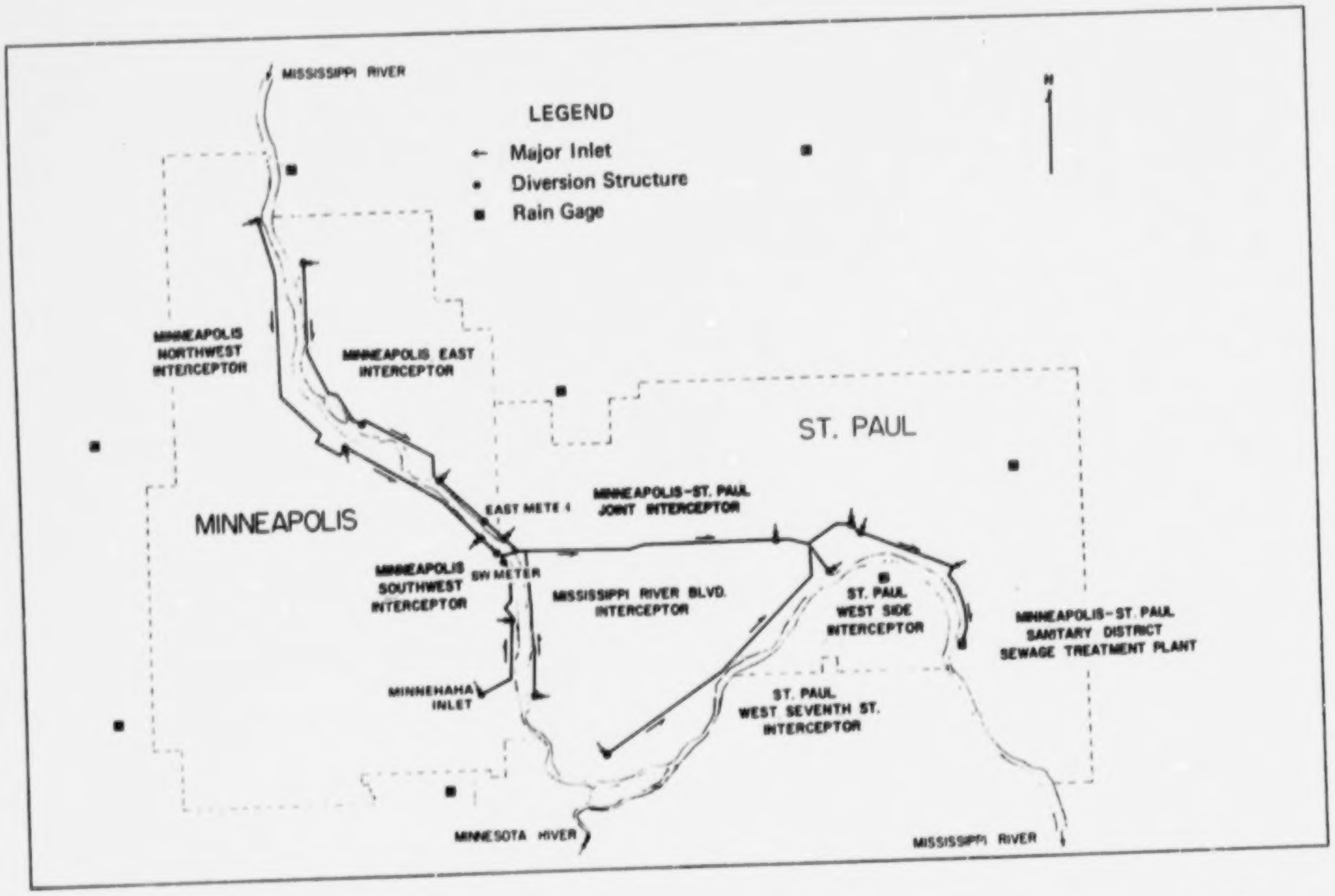
MISSISSIPPI RIVER
LEGEND
← Major Inlet
• Diversion Structure
■ Rain Gage
N
MINNEAPOLIS NORTHWEST INTERCEPTOR
MINNEAPOLIS EAST INTERCEPTOR
ST. PAUL
MINNEAPOLIS
EAST METER
MINNEAPOLIS-ST. PAUL JOINT INTERCEPTOR
MINNEAPOLIS SOUTHWEST INTERCEPTOR
SW METER
MISSISSIPPI RIVER BLVD. INTERCEPTOR
ST. PAUL WEST SIDE INTERCEPTOR
MINNEAPOLIS-ST. PAUL SANITARY DISTRICT SEWAGE TREATMENT PLANT
MINNEHAHA INLET
ST. PAUL WEST SEVENTH ST. INTERCEPTOR
MINNESOTA RIVER
MISSISSIPPI RIVER

Figure 1. Map of Twin City area showing location of interceptor sewers, major inlets, diversion structures, and rain gages.

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II. GENERAL CONCEPT OF MODEL

The mathematical model (UROM-9, Urban Runoff Model PDP-9) is a deterministic runoff model capable of continuous real-time operation. Input to the model consists of rainfall readings and postulated gate and fabridam settings. Output can range from a simple message to the operator, to complete rainfall and loss rate analysis, diversion analysis, and predicted hydrographs at points in the sewer system. The operator can interact with the model while it is operating in real time to alter the sequence of operations, postulate new gate and fabridam settings, and change the model output. In addition the model can be set to operate on historical or design rainstorms. The operation of the model is discussed in detail in Appendix A, Operator's Manual for UROM-9.

To make the model easier to understand and to work with it has been broken down into a series of simple tasks, each of which is carried out by a subroutine. As each subroutine completes its task it passes the results to another routine until the entire model has been executed. This process can be illustrated as follows: The rainfall data that are given to the model may contain various errors of electronic, mechanical, or human origin. Thus the model's first task is to screen the rainfall data for errors and make reasonable corrections. This task is performed by a subroutine entitled RAINF. Since the rainfall data may have been recorded at any random time interval, the next task is to space the data at some regular interval (usually 5 minutes); this task is performed by subroutine EVNTL. The next step is to determine what portion of the rainfall can be expected to be "lost" to the ground and what portion will become runoff. Subroutine SLOS performs this task. These are only a few of the steps in the overall model.

It can be seen that changes in methods are easily implemented. If a different loss analysis is desired, for example, the change can be made by simply replacing the current version of SLOS with a new version containing the new loss analysis. The subroutines are not concerned with the particular area modeled, but simply perform their functions on the data given them.

The model is applied to a given area by supplying it with input data describing the physical features of the area. These input data include the number of sub-watersheds the total area is broken into, their areas, their times to peak, and the base times of their unit hydrographs. All input data is given in Appendix A. In the preceding example, subroutine RAINF would be fed the number of rain gages in the system, subroutine EVNTL would be told at what regular interval to space the rainfall data, and subroutine SLOS would be given several parameters for each sub-watershed which would relate the amount of pervious and impervious area, the initial depression storage, the infiltration constants, and other variables depending on the particular loss analysis used. Thus the methods used are governed by the subroutine instructions, while the application to an area is governed by the input data to the subroutines.

Some restrictions on the general applicability of the model are as follows:

1. Storage requirements set an upper limit on the size of input data arrays which in turn limits such things as the number of sub-areas that can be modeled. The upper limit can change depending on computer storage available.
2. Variations in the sizes of data arrays may require minor changes in the format of the output data.
3. Certain aspects of diversion structure modeling are not general in nature, but apply only to the area to which the model is being applied.

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III. SPECIFIC MODELING TECHNIQUES

For purposes of discussion the model can be divided into three phases: the hydrology phase, the diversion phase, and the routing phase. The hydrology phase is the period between the time the storm water appears as rainfall and the time it arrives at the inlets to the interceptor sewer system. The diversion phase determines, for given positions of the rubber fabridam and variable gate, how much of the arriving flow will enter the interceptor sewers and how much will be diverted to the river. Finally, the routing phase predicts the movement of the flow that enters the interceptor sewers. Further discussion of each of these phases is given below.

A. Hydrology Phase

In this phase rainfall from a network of recording gages is converted to runoff at the major inlets to the interceptor system. The first step in the process deals with the mechanics of input of the rainfall data (For additional information on these steps see Appendix C.) This step provides corrected rainfall readings at each gage in the network at regular time intervals, usually 5 minutes. From these raingage readings the average rainfall over each sub-watershed is determined, using the Thiessen method [2]; this consists of weighting each raingage by a factor dependent on the location of the gage relative to the sub-area. During the 1969 runoff season a network of eight recording raingages supplied data to the model. Figure 2 shows the Thiessen polygons used to determine the weighting factors for an eight-gage network with 15 sub-areas. At the end of the year (1969) a ninth recording gage was added. Future changes may also be made in the locations of some existing gages.

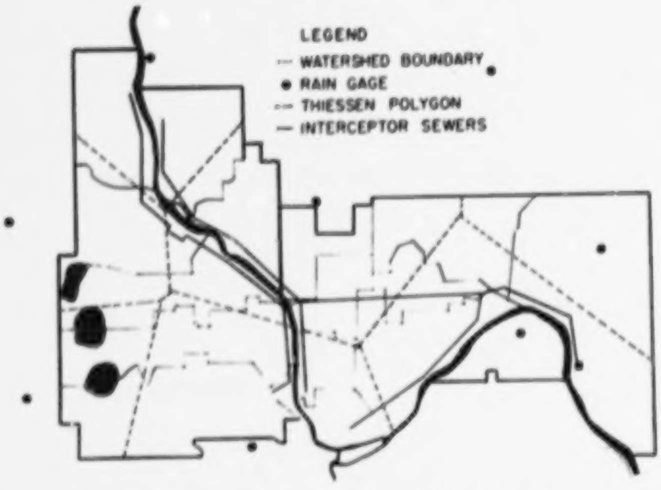

Figure 2. Map of Twin City Area showing major watersheds and Thiessen polygons.

Next the losses and the excess precipitation to be expected in each of the sub-areas must be found. The "loss" is that part of the total precipitation which is retained in the sub-area, while the "excess" is the portion that becomes runoff and enters the sewer system. Predicting the losses that will occur during a particular rainfall event over a particular area is probably the most difficult task of the model. Several approaches have been considered. The current method determines separately the losses on the impervious surfaces (i.e., paved areas) and those on the pervious surfaces (grassy areas) and then combines them, taking into account the relative amounts of pervious and impervious surface in the sub-area.

These relative areas were estimated using aerial photographs of representative areas of the Twin Cities. Photos on a scale of either one inch equals 100 ft or one inch equals 200 ft, covering areas of approximately 0.1 sq mi and 0.4 sq mi, respectively, were overlaid with a 1/4 inch or a 1/8 inch uniform grid, and grid squares enclosing impervious surfaces were counted. Only effective impervious surface area was included; where runoff from rooftops would drain across lawns, for example, the rooftops were not considered impervious area. The proportion of impervious area was found to vary from 96 per cent for a downtown business area to 26 per cent for a single-family residential area. The average for Minneapolis and St. Paul combined is 35 per cent.

Impervious Analysis—The excess from impervious areas is assumed to depend on (1) the rainfall, (2) an antecedent index parameter, and (3) three constants. The antecedent parameter is the accumulated loss—i.e., the moisture retained—on the impervious surfaces; this is presently taken to be zero at the beginning of an event. The first constant is the value of the accumulated loss that must be reached before any runoff will occur. This value may take into account interception by trees and wetting of land surfaces. Zero is presently used for this initial loss constant. Once the initial loss has been satisfied, the loss is determined as follows:

$$\text{Loss} = \text{Rainfall} \times \text{loss coefficient} \qquad (1)$$

where

$$\text{Loss coefficient} = Ce^{-k\,(\text{accumulated loss})} \qquad (2)$$

and C and k are constants for a sub-watershed (assumed to be 1.0 and 2.0, respectively.) Figure 3a shows this loss coefficient as a function of accumulated loss on the impervious area. The loss coefficient decreases asymptotically from an initial value of 1.0 for completely dry conditions to a value of zero for wet conditions. Thus for dry conditions the entire rain is retained as loss on the impervious surfaces. As moisture builds up, depression storage is filled and the loss coefficient decreases, allowing a portion of the

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rainfall to become runoff. Figure 4a shows the actual loss rate when this same function is applied to a uniform one-inch-per-hour rain.

The impervious excess is then

$$\text{Impervious Excess} = \text{Rainfall} - \text{loss} \qquad (3)$$

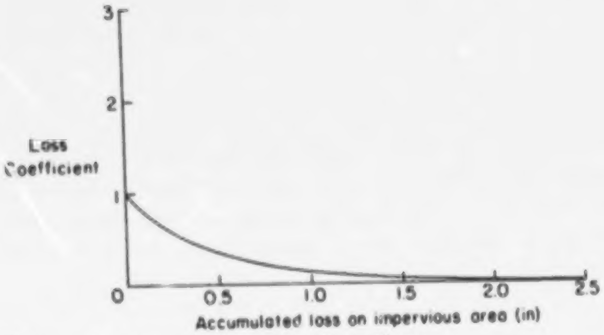

Figure 3a. Impervious loss function.

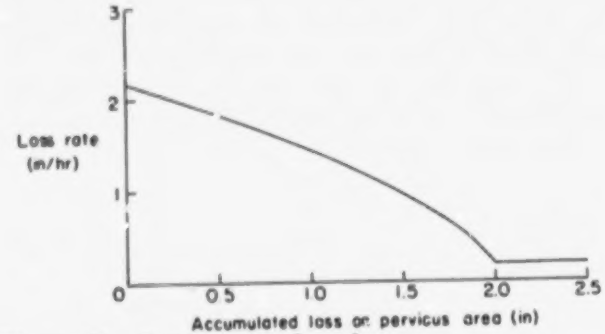

Figure 3b. Pervious loss function.

Pervious Analysis—The excess from pervious areas is assumed to depend on (1) the rainfall, (2) an antecedent index parameter, and (3) four constants. The antecedent parameter is the accumulated loss on pervious surfaces—i.e., the moisture retained by the soil in a given layer. This value is presently taken as zero at the beginning of an event. The first constant is an initial value of the accumulated loss that must be satisfied before any runoff can occur; a value of 0.25 in. has been used here. Once the initial loss has been satisfied, the loss rate is determined using the Holtan infiltration equation as modified by Huggins and Monke: [3]

$$f = fc + A\left(\frac{T - (\text{accumulated loss})}{T}\right)^k \qquad (4)$$

where f is the potential infiltration rate (in. per hr); fc is the constant equilibrium infiltration rate, taken to be 0.2 in. per hr; A is the increase in infiltration rate under dry conditions, assumed to be 2.0 in. per hr—giving a total infiltration rate of 2.2 in. per hr when the soil is dry; T is the total available storage in the soil above the restricting layer, assumed to be 2.0 in.; and k is a constant taken as 0.7.

Figure 3b shows the potential loss rate as a function of the accumulated loss on the pervious area. The loss rate decreases from an initial value of 2.2 in. per hr for completely dry conditions to a value of 0.2 in. per hr for wet conditions. This same loss rate applied to a one-in.-per-hour rain is shown in Fig. 4b. Under these conditions it may be noted that for the first 1-2/3 hrs of the storm the rainfall rate is lower than the potential loss rate, so the actual loss rate is equal to the rainfall rate. During the remainder of the storm the potential loss rate is lower than the rainfall rate. At 2-1/3 hrs the potential loss rate has decreased to its equilibrium value (0.2 in. per hr). Thus when the rainfall is less than the potential loss rate, the actual loss rate is equal to the rainfall rate; but when the rainfall equals or exceeds the potential loss, the actual loss rate is equal to the potential loss rate, which in turn equals the equilibrium value fc. The excess on the pervious areas is then given by

$$\text{Pervious excess} = \text{rainfall} - \text{loss} \qquad (5)$$

and the sub-watershed excess is given by

$$\text{Basin excess} = \frac{x}{100}\,(\text{impervious excess}) + \frac{(100 - x)}{100}\,(\text{pervious excess}) \qquad (6)$$

where x is the percentage of sub-area that is impervious.

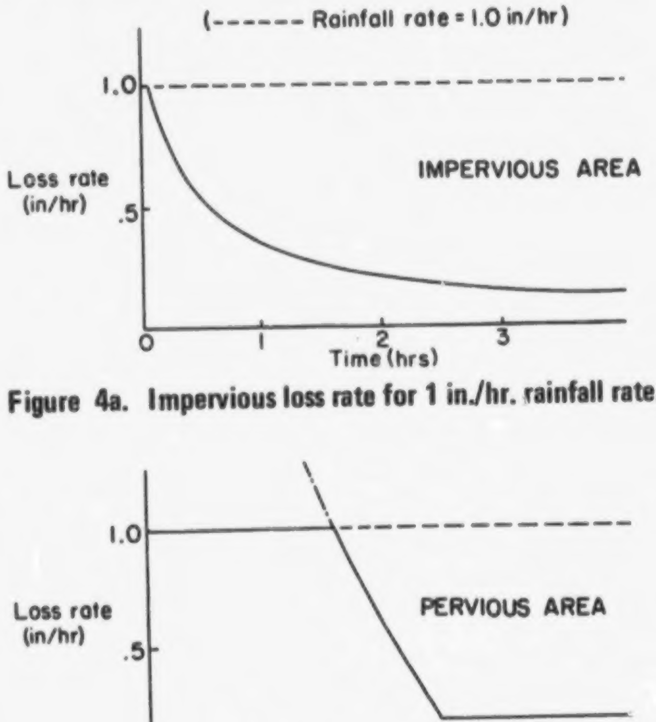

Figure 4a. Impervious loss rate for 1 in./hr. rainfall rate.

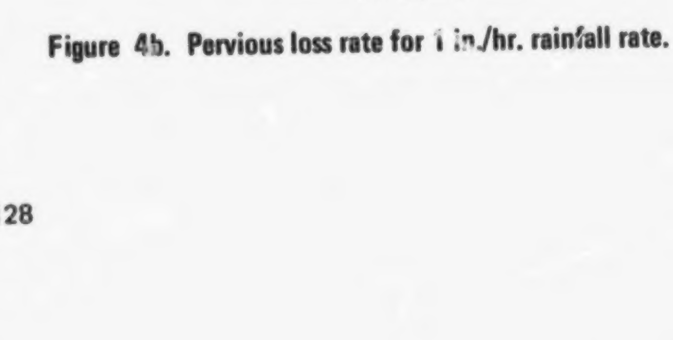

Figure 4b. Pervious loss rate for 1 in./hr. rainfall rate.

Figure 4c shows the results when the complete loss rate is applied to an area that is 1/3 impervious with a one-in.-per-hour rainfall. The area between the time axis and the loss curve represents the total loss over the sub-watershed, while the area between the loss curve and the dashed one-in.-per-hour line represents the total excess over the sub-watershed. This excess will become runoff at the inlet to the interceptor sewer.

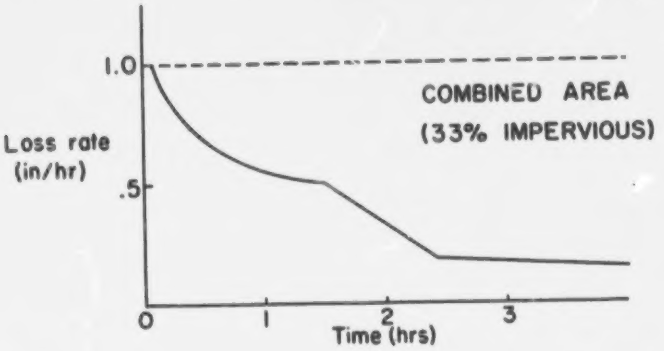

Figure 4c. Combined loss rate for 1 in./hr. rainfall on a watershed 1/3 impervious.

An important feature of this loss analysis is that the independent variable is accumulated loss (moisture retained in the watershed), whereas in other loss analyses—Horton's [2], for example—time is the independent variable. Since under real conditions there are often periods of low or zero rain during a prolonged storm, an analysis based on time requires additional techniques, such as time condensation. In addition to simplifying the process, the use of accumulated loss as the independent variable allows for a recovery or draining feature to be incorporated into the analysis which would describe the return to dry conditions during periods of no rain. Presently no recovery feature is included in the model.

The determination of the hydrographs at the inlet, is next. The excess water, determined in the above loss analysis, arrives at the interceptor sewer inlet; it is assumed that this quantity of water is spread uniformly over the sub-watershed. Several approaches to determining the hydrograph, or time distribution, of this runoff have been proposed. The unit hydrograph approach used here is based on the theory that when the water drains to the watershed outlet (i.e., the interceptor inlet) it does so according to a given time pattern which is assumed to depend on the physical features of the area—its size, shape, slope, etc. The theory further assumes that if different amounts of water occur as runoff, the magnitude of the runoff changes proportionately, but the time pattern does not change.

The shape of the unit hydrograph is most reliably determined from recorded events that have occurred on the watershed. Since this information was not available in the present case, some characteristics of the unit hydrograph were estimated from the physical features of the sub-watersheds, and a triangular shape was assumed. The estimated characteristics were the time to peak T_p and the base T_b. As a first approximation T_p and T_b were determined from the relationship given by Kent [4]:

$$T_p(\text{hrs}) = \frac{D}{2} + \frac{L^{0.8}\left[\left(\frac{1000}{CN} - 10\right) + 1\right]^{1.67}}{9000\ Sa} \quad (7)$$

where D is the duration of rainfall increment (hr), L is the length of mainstream to farthest divide (ft), CN is the SCS hydrologic soil-cover complex number, Sa is the average slope of the watershed (per cent) along the mainstream, and

$$T_b\ (\text{hr}) = 2.67\ T_p \quad (8)$$

Kent provides a nomograph for the solution of the second term of Eq. (7). The peak discharge of the unit hydrograph would then be given by

$$Q_p\ (\text{cfs}) = 0.0000464\ \frac{AR}{T_b} \quad (9)$$

where A = area (ft^2), R = rainfall excess (in.), and T_b = base time (hr).

The initial values of T_p and T_b given by Eqs. (7) and (8) have been modified in some cases as recorded data have been obtained by the data acquisition system at the MSSD treatment plant. The T_p and T_b given by Eqs. (7) and (8) have agreed reasonably well with values obtained from recorded data.

The duration of the unit impulse is selected as 5 minutes. Thus each 5-minute rain period yields a runoff hydrograph. These incremental hydrographs are combined linearly and base flow is added to form the total inlet hydrograph. The mean annual base flow is used at each inlet with average hourly variations imposed on it.

The formation of the total inlet hydrograph, completes the hydrology phase of the model. Additional discussion of hydrology phase may be found in reference [5].

B. Diversion Phase

In this phase the total inlet hydrographs, as determined in the hydrology phase, are passed through the simulated diversion structures to provide an estimate of how much of the flow will enter the interceptor sewer and how much will enter the Mississippi River. The amount of flow that enters the interceptor sewer system will then be passed on to the routing phase of the model.

To accomplish the diversion simulation each major diversion structure was analyzed and then represented by a combination of orifices, weirs, and pipe sections for which discharge equations were prepared. Several structures are similar in geometric configuration, while others are of unique design, occurring only once in the sewer system. The most common type of diversion structure is composed of (1) an outlet from the trunk sewer to the interceptor sewer controlled by a hydraulically operated gate and (2) a tunnel to the river controlled by a pneumatically operated fabridam. Such a structure is shown in Fig. 5. This configuration is referred to as a TYPE 1 diversion structure. The gate opening is modeled as a variable-area orifice and the fabridam as a variable-height weir. [6]

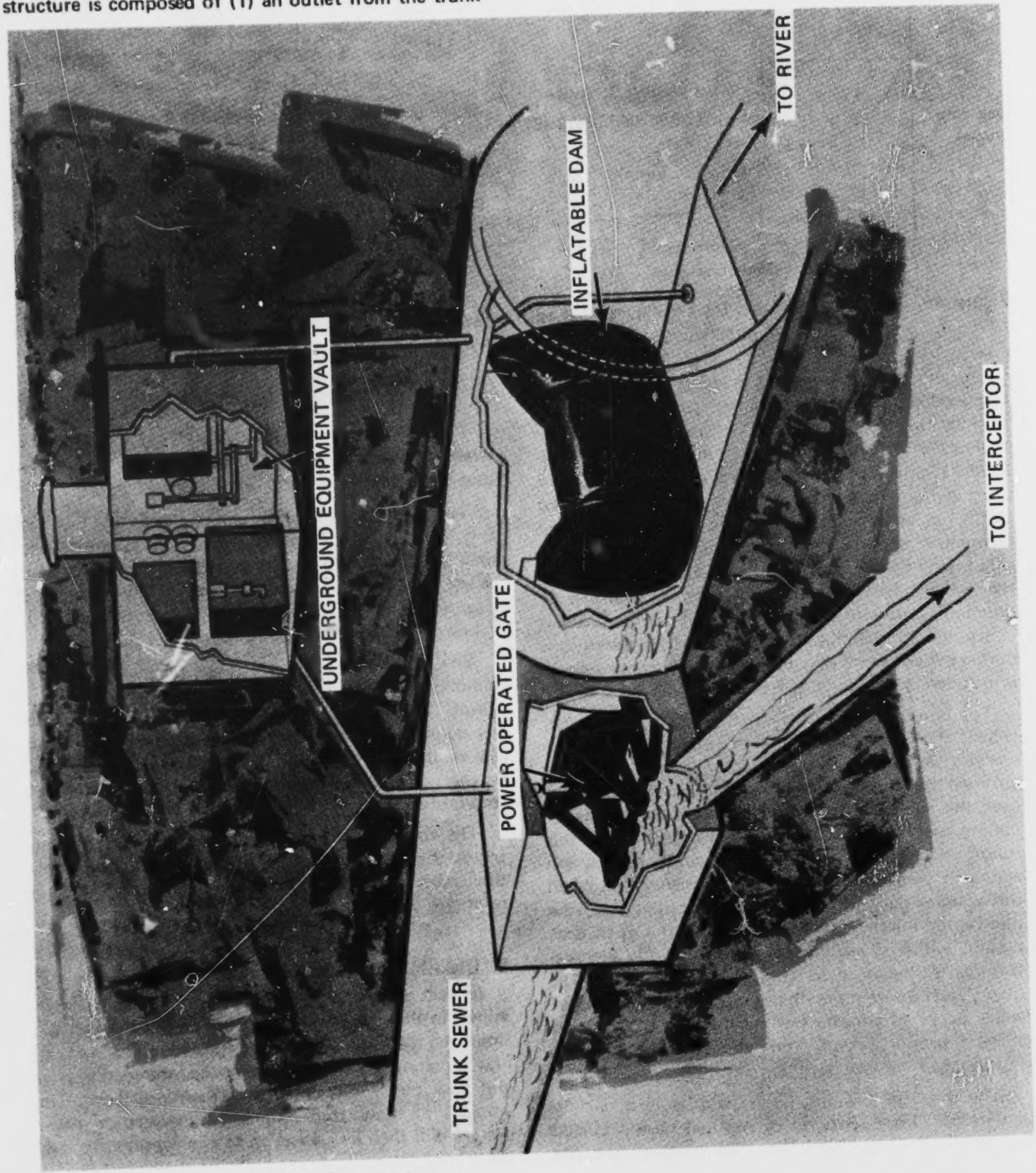
TO RIVER
INFLATABLE DAM
UNDERGROUND EQUIPMENT VAULT
TO INTERCEPTOR
POWER OPERATED GATE
TRUNK SEWER

Figure 5. Typical Type 1 diversion structure.

The flow coming down the trunk sewer is assumed to take one of two paths: either through the gate to the interceptor or over the fabridam to the river. Actually, some of the flow must go into temporary storage in the trunk sewer, but this flow is not modeled. The portions of the trunk flow which go to the interceptor and to the river can be determined from the gate opening and the fabridam height. The discharge Q_O that will pass through the orifice with a driving head equal to the fabridam height can then be found. If Q_O is greater than the flow coming down the trunk, all the flow will go through the orifice to the interceptor sewer. If Q_O is less than the trunk flow, part of the flow will go through the orifice and part will go over the fabridam. In this latter case a common head must be found such that the sum of the discharges over the weir and through the orifice equals the trunk flow. This result is found using an iterative procedure (method of bisection). Figure 6 shows two complete solutions of a TYPE 1 diversion with the fabridam both down and up, and each with three different gate openings (0.25 ft, 0.75 ft, 1.25 ft). For the fabridam up and the 1.25 ft gate opening, it can be seen that when the trunk flow is less than 50 cfs the entire flow will go through the orifice to the interceptor. For discharges greater than 50 cfs only part of the flow goes to the interceptor, and the remainder goes over the fabridam to the river. Thus for a trunk flow of 100 cfs the interceptor flow will be 60 cfs and the river flow will be 40 cfs. Once flow has started over the fabridam only small increases in interceptor flow occur for large increases in trunk flow. This is due to the difference between the exponent for flow over a weir (1.5) and that for flow through an orifice (0.5) and the difference in datum for the heads.

The diversion structure thus acts to clip off the higher flows, sending only a regulated amount to the interceptor sewers.

The clipping action of the diversion structures increases the accuracy of the model prediction. If the loss rate analysis predicts rainfall excess equal to or greater than the actual values, the inlet hydrograph will be either correct or over-estimated. The diversion structure will then cause the excess flow to be discharged into the river. Thus the amount that enters the interceptor, which is of primary interest, is more nearly correct, with the errors going to the river. Figure 7 illustrates this effect. Curve 1 represents a computed inlet hydrograph that may be in error, Curve 2 shows the portion of this hydrograph that would enter the interceptor, Curve 3 represents the actual inlet hydrograph, and Curve 4 shows the portion of this actual hydrograph that would enter the interceptor. Therefore, while there are large differences between 1 and 3 (that is, before diversion), there are only small differences between 2 and 4, after diversion. This, of course, holds only when the true inlet hydrograph is large enough to cause diversion to the river.

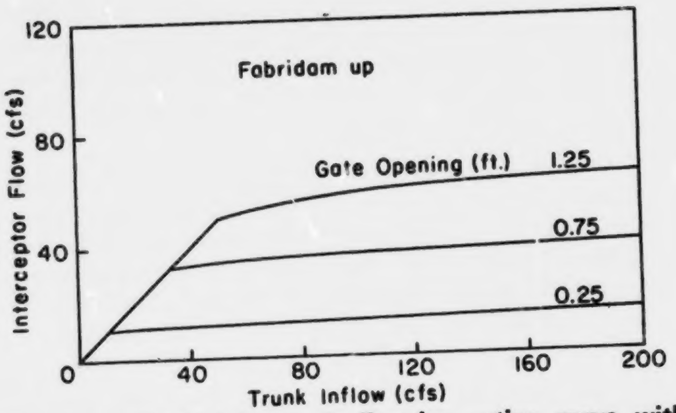

Figure 6a. Typical Type 1 diversion rating curve with fabridam up.

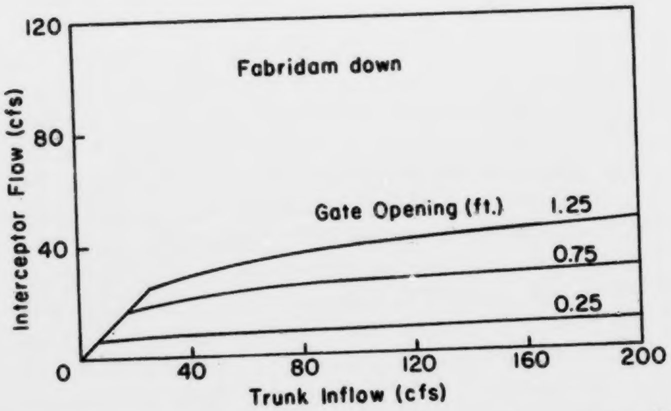

Figure 6b. Typical Type 1 diversion rating curve with fabridam down.

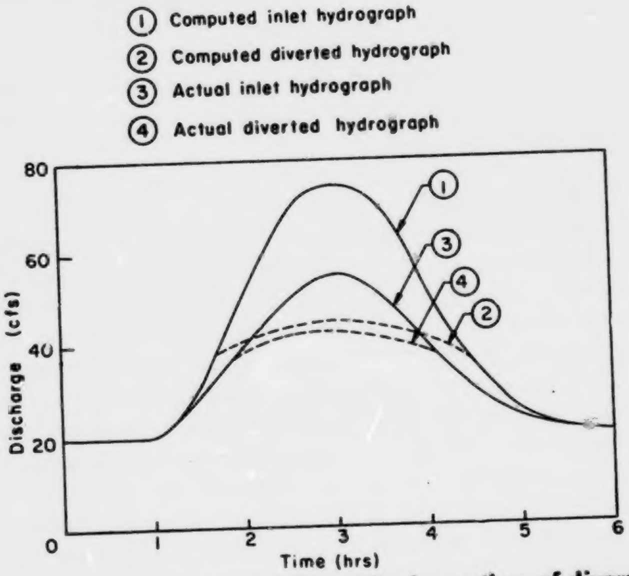

Figure 7. Illustration of flow clipping action of diversion structure.

The TYPE 1 diversion structure occurs ten times in the sewer system. The model includes nine other locations where flow may be diverted to the river. Three of these are modeled as sharp clipping devices (i.e., all discharge above a fixed value is released to the river). Another three occur at the Minneapolis discharge meters and are modeled as variable bypass gates only. The remaining three are each special cases and are handled individually. A complete discussion of each structure is given in Ref. [7].

The land area that contributes storm runoff to the interceptor system at the 15 major inlets represents 61 per cent of the total area contributing runoff to the system. The remaining area contributes storm water to the system through about 47 minor inlets. Diversion to the river may occur at the 15 major inlets plus 4 more structures such as venturi meters.

To allow for the minor inlet flow the contribution of each minor inlet is assumed to enter the sewer system at the nearest major inlet. All model computations through the diversion phase are based on the actual area contributing at a major inlet. After diversion is complete the diverted hydrographs are corrected by multiplying the discharges by the inlet lumping factor, which is taken as the ratio of the area assumed to contribute to a major inlet to the actual area that contributes to the inlet. In other words, the minor inlets are assumed to behave in a manner which is hydraulically similar to that of the major inlets. The largest area represented in this manner is at the Phalen Creek inlet. In this case the actual area contributing to the inlet is 2.06 sq mi, and multiplying by the lumping factor of 3.96 gives an assumed or lumped area of 8.15 sq mi. Most of the lumped area here is from the Beltline trunk sewer. The dry-weather connections from the trunk sewer to the interceptor sewer for both the Phalen Creek inlet and the Beltline inlet have low capacities. Only a small portion of the total trunk sewers capacity can enter the interceptor. For this reason the lumping of such a large area at the Phalen Creek inlet does not adversely affect the accuracy of the model prediction.

C. Routing Phase

General Discussion—The third phase of the study covers the routing of the flow through the interceptor system. Available methods permit a much better prediction of the routing process than they do of runoff or diversion. The "method of characteristics" was selected for initial routing of the hydrographs. The usual methods of hydrologic routing are based primarily on the equation of continuity with constants or simple relations used to account for momentum effects. The method of characteristics is one of several methods of mathematical routing which solve the equations of momentum and continuity. This method has been proven in the literature to accurately represent unsteady, gradually varied flow in open channels.

It was found that for the large system of open channels which makes up the interceptor system, the method-of-characteristics solution requires a considerable amount of computer time, and therefore a method was sought which would produce the same answers using less computer time. It was found that the "progressive average-lag method" from Ref. [8] accomplished this objective if the constants used were determined by comparing input and output hydrographs with those obtained from the method of characteristics.

Method of Characteristics—The equations of continuity and momentum for unsteady, gradually varied open channel flow are

$$\frac{V}{A}\frac{\partial A}{\partial x} + \frac{1}{A}\frac{\partial A}{\partial t} + \frac{\partial V}{\partial x} = 0 \qquad (10)$$

and

$$g\,\frac{\partial y}{\partial x} + g\,(S - S_o) + V\,\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} = 0 \qquad (11)$$

where

V	is the mean velocity at any instant t and position x
y	is the depth of flow at any instant t and position x
A	is the corresponding cross-sectional area
x	is the distance measured along the channel
t	is the time
S	is the energy slope
S_o	is the bed slope.
g	is the acceleration due to gravity.

These equations can be written in finite difference form for integration along what are known as the characteristic curves as follows:

$$\left.\begin{aligned} &V_p - V_R + \sqrt{\frac{gT_R}{A_R}}(y_p - y_R) + g(S_R - S_o)\,\Delta t = 0 && (12)\\ &x_p - x_R = (V_R + \sqrt{\frac{gA_R}{T_R}})\ \Delta t && (13)\end{aligned}\right\} C+$$

$$\left.\begin{aligned} &V_p - V_S - \sqrt{\frac{gT_S}{A_S}}(y_P - y_S) + g(S_S - S_o)\,\Delta t = 0 && (14)\\ &x_P - x_S = (V_S - \sqrt{\frac{gA_S}{T_S}})\,\Delta t && (15)\end{aligned}\right\} C-$$

The first two equations refer to integration along the C_+ characteristics shown in Fig. 8, while the second two refer to the C_- characteristic.

The reader is referred to Ref. [9] for the derivation of these equations. The subscripts in the equations refer to the points P, R, and S in Fig. 8. The values of velocity and depth at R and S are found by interpolation between known values at the grid points A, B, and C. As indicated in Ref. [9], these equations can be

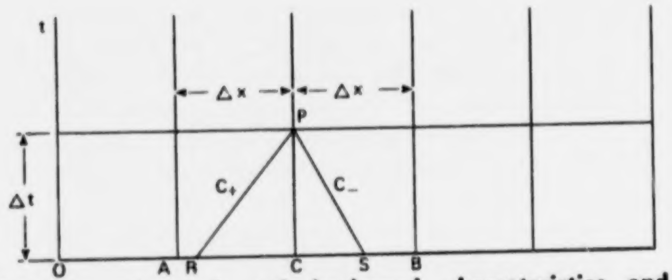

Figure 8. Forward and backward characteristics and definition of grid points.

solved to determine the velocity and depth at all points like P which are Δt later than the points like C, at which conditions are known from previous calculations. In other words, the flow can be represented on the x – t plane, as shown in Fig. 8. At every point on the grid the velocity and depth must be calculated using a procedure which is similar to extrapolation.

The boundary conditions are important in this process, and they give some information in the x – t plane about the depth and the velocity at all points on the lines x = 0 and x = L, where L is the total length of the channel. The boundary conditions, which are discussed in Ref. [10], are

a. Critical flow at the downstream end of a channel
b. Inflow hydrograph at the upstream end of a channel
c. Inflow hydrograph in the middle of a channel
d. Junction of a number of channels.

At the end of the channel only one pair of characteristics equations applies (i.e., either a C_+ or a C_- characteristic–see Fig. 9). The other equation in the case of critical flow, for instance, is

$$V_P = \frac{gA_P}{T_P} \qquad (16)$$

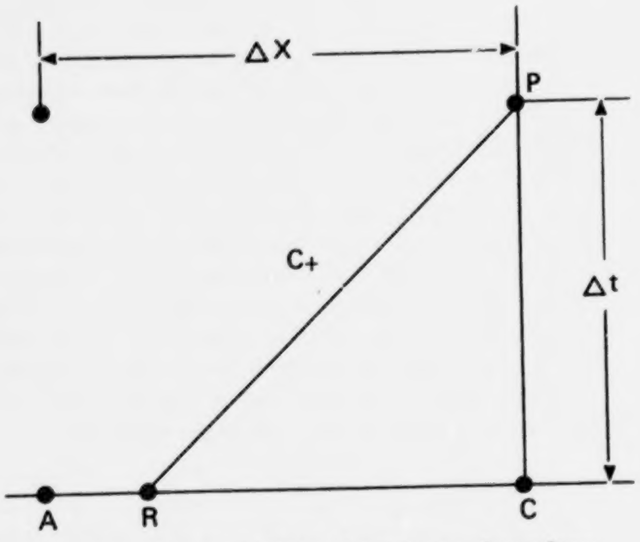

Figure 9. Characteristic at downstream boundary.

Thus in the case of critical flow Eqs. (12), (13), and (16) can be solved to determine V_P and y_P. The details of the derivation of the boundary conditions are given in Ref. [10].

It was found that the interceptor sewer system could be broken up into a series of 23 open channels, each with one of the above boundary conditions at its two ends. The critical flow condition commonly occurs at the downstream end of the channel, while input hydrographs commonly enter through a diversion structure and drop shaft either at the upstream end of the interceptor or in the middle of it. The junction conditions occurs only once.

A typical solution for a channel is shown in Fig. 10. It can be seen that the hydrograph is attenuated as it flows downstream and is displaced along the time axis.

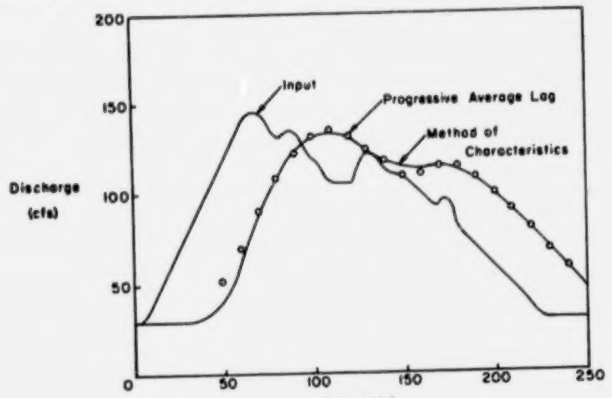

Figure 10. Results of routing irregular hydrograph by the method of characteristics and by the progressive average lag method.

Many different numerical tests have been conducted using the characteristics routing method on various channels; a resume of the results is as follows:

1. There is a maximum allowable rate of rise or fall in the input hydrograph for a given channel subdivided into certain reach lengths. This rate is at present found by trial and error.
2. The program has been compared with numerical and actual results from work at Colorado State University (sponsored in part by the Bureau of Public Roads) as reported by Mitchell in Ref. [11]. The numerical results calculated in the present study are indistinguishable from those calculated by Mitchell, and both of these agree reasonably well with measured values.
3. A comparison has been made between results for a circular cross section and for a rectangular cross section in a channel of fixed length using the same input hydrograph for both configurations. The rectangular channel width was the diameter of the circle, and the hydraulic radii of the two were the same when the circular channel was half full. The outflow hydrographs in the two cases are so similar

that the routing process does not seem to depend too closely on the cross-sectional shape for relatively minor differences in shape.

4. The attenuation of the peak of the hydrograph depends on the shape and size of the input hydrograph.
5. The rate of travel of the peak of the hydrograph is dependent on the shape and size of the input hydrograph.

Progressive Average Lag Method

As previously mentioned, the method of characteristics requires a comparatively large amount of computer time, and a simpler method which would produce the same results was sought to facilitate rapid computation of hydrographs while rain is still falling. As mentioned in Ref. [10], quite a number of different methods were tried, including the Muskingum. The method initially selected as a substitute is the progressive average-lag method (Ref. [8]), and this has been incorporated in program UROM 9.

The method has several variations, but it is best described as shown in Fig. 11. The value of q_{ni} on the routed hydrograph depends on the average of a number of equally spaced values of q on the inflow hydrograph. In the figure q_{ni} is given by

$$q_{ni} = 1/3\,(q_{i-2} + q_{i-1} + q_i) \tag{17}$$

Generally

$$q_{ni} = \frac{1}{n} \sum_{j=i-n}^{i} q_i \tag{18}$$

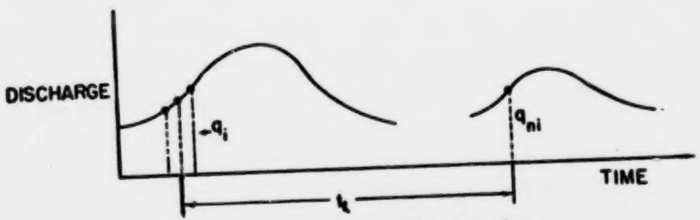

Figure 11. Progressive average lag routing.

where n is the number of points to be averaged. The lag time t_ℓ is determined empirically, from known flow times, or from the method of characteristics.

Successive use of Eq. (18) will determine the routed hydrograph at the end of a certain reach. The process can be repeated over the next reach downstream with the first routed hydrograph becoming the input hydrograph.

In this project the values of n and t_ℓ and the number of reaches required for a given channel have been determined by trial and error. The input and routed hydrographs calculated by the method of characteristics for the particular channel have been taken as correct and different values of n and t_ℓ tried until the routed hydrographs coincided. Again reference is made to Fig 10, where the points plotted represent the routed hydrograph which best conforms to the hydrograph calculated by the method of characteristics. It can be seen that there is good agreement between the two methods. Similar results were obtained for other conduits with diameters ranging from 4.44 to 13.83 ft and lengths from 2000 ft to 23,500 ft. As many as three input hydrographs have been used as input data for a particular channel, and the same routing constants gave good answers in each case.

It was concluded that the progressive average-lag method of routing produces the correct routed hydrographs for the channels investigated if the appropriate routing constants are used. The progressive average-lag method is considerably faster than the method of characteristics, and hence it has been used in the real-time program UROM 9.

In addition to routing flow, the routing phase of the model must perform two additional functions: the combining of flow and the diversion of flow. Combining of flow takes place either where additional flow enters an interceptor at an inlet or where two interceptors meet. Combining is accomplished by simple addition of the flows; this follows from the superposition principle of unit hydrograph theory.

Diversion of flow sometimes occurs after the flow has already entered the interceptor lines. This kind of diversion may occur at five points in the interceptor system to prevent overloading of the main interceptor lines.

The routing phase of the model contains the subroutines necessary to perform each of the three operations—routing, combining, and diversion. A table of input data determines which of the three operations should be carried out and provides an index as to which hydrographs are involved. The steps listed in the table are carried out in sequence until all operations have been completed. The program instructions are thus independent of the area modeled. The data table is in effect a map that shows the layout of the sewer system and the locations of the inlets and diversion structures. Thus by adding entries to or removing entries from the table, sewer lines can be added or removed from the system. Inlets and diversion structures can be added or removed in the same way.

IV. DISCUSSION OF METHODS

Throughout the model various methods are used to simulate the runoff process. Some of these methods are linear and some are non-linear. Linear methods are used where the results obtained are believed to be within the degree of accuracy desired or where the information is such that only linear methods can be used.

Initially the precipitation data are given for each raingage as a function of time at some irregular time spacing. Linear interpolation is used to determine equivalent rainfall data spread at regular intervals (usually 5 minutes). Since the model must operate in real time up to the latest rainfall reading available, the interpolation can be based only on readings taken prior to the current readings—the future trend being unknown—and a linear interpretation is justified.

The areal distribution of precipitation over each sub-watershed is found by the Thiessen method. An alternate method based on isohyetal maps of the precipitation, according to which the isohyetal lines are determined by linear interpolation between stations, has been found by Kwan [12] to give results which agree well with those of the Thiessen method, and this agreement served to substantiate the use of the more rapid Thiessen method.

Determination of the sub-watershed losses and the resulting excess precipitation is a non-linear process and has been modeled as such.

The unit hydrograph method is used in this program to determine the inlet hydrograph resulting from excess precipitation. It has been shown by Machmeier and Larson [13] and others that the runoff process is actually non-linear. With increased excess precipitation the magnitude of the peak discharge increases non-linearly. In addition, the time to peak discharge decreases. Most of these studies were concerned with basins possessing "natural" characteristics. For urban sewered areas other conditions might cause the runoff process to behave quite differently. Changing control at different discharges can cause marked changes in the runoff distribution. This may result from constrictions in the system, clogging of inlets, or various other factors. Also, a sewered area is actually served by two drainage systems, the primary system (i.e., the storm sewers)—which is designed to handle flows up to a given design value—and the secondary system (i.e., natural or manmade surface drainage), which should be available to handle flows above the design value of the primary system. Factors such as these may well mask out or reverse the commonly expected "non-linear effects." Thus it was felt that at least for the initial approach to the formation of the inlet hydrograph, the unit hydrograph method is justified.

The diversion structure analysis, as shown previously, is non-linear when the discharges in the trunk sewer cause overtopping of the fabridam. The use of the lumping factor to account for area not actually contributing to a major inlet assumes a linear relationship between the response of the actual contributing area and the total lumped area. This assumption provides an easy method of accounting for flow entering at major inlets. The use of the lumping factor tends to overemphasize the effect of some of the variable diversion structures.

The progressive average-lag routing method is entirely linear.

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V. MODEL PERFORMANCE FOR NATURAL EVENTS

Rainfall for the months of June, July, August, and September of 1969 was 7.36 inches. The normal expected for this period would be 12.88 inches. The dryness of the 1969 runoff season, in combination with hardware and software problems of a new computer system, limited the number of runoff events that were recorded during 1969. From the data that were available, four events were selected on which to test and fit the runoff model. These four events occurred on Julian days 207, 211, 218, and 267, which correspond to July 26, July 30, August 6, and September 24, 1969 respectively. The precipitation characteristics for each of these storms are shown in Figs. 12a, b, c, and d, respectively. The areal distribution of precipitation for the entire storm is shown by the isohyetal lines in the figures. The time distribution is given for four of the recording gages in the network.

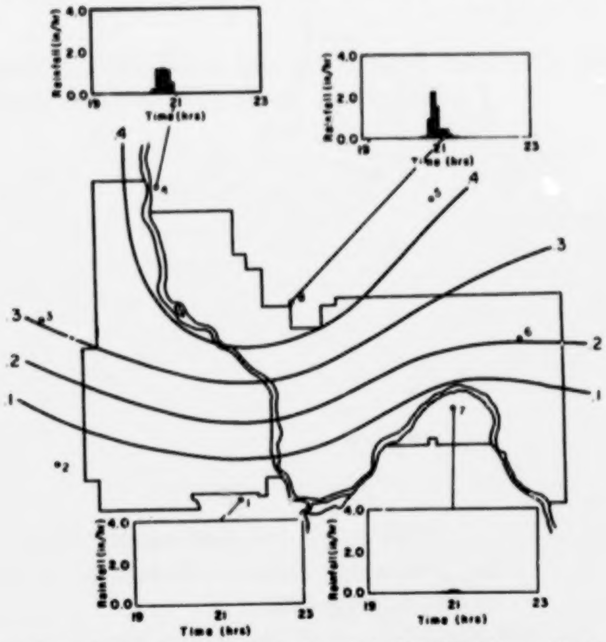
Rainfall (in/hr)
4.0
2.0
0.0
19
21
23
Time (hrs)
4
3
2
1
3
2
1

Figure 12a. Temporal and areal distribution of storm on day 207 (July 26, 1969)

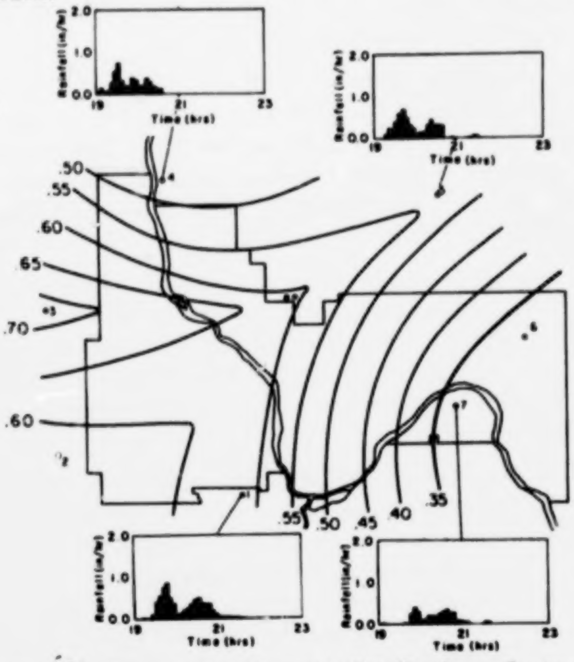
Rainfall (in/hr)
2.0
1.0
0.0
19
21
23
Time (hrs)
.50
.55
.60
.65
.70
.60
.55
.50
.45
40
35

Figure 12b. Temporal and areal distribution of storm on day 211 (July 30, 1969)

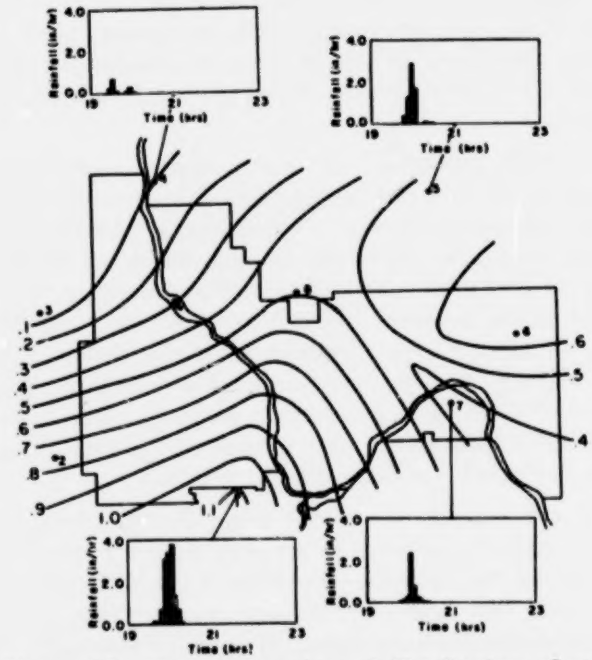
Rainfall (in/hr)
4.0
2.0
0.0
19
21
23
Time (hrs)
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
.6
.5
.4

Figure 12c. Temporal and areal distribution of storm on day 218 (Aug. 6, 1969)

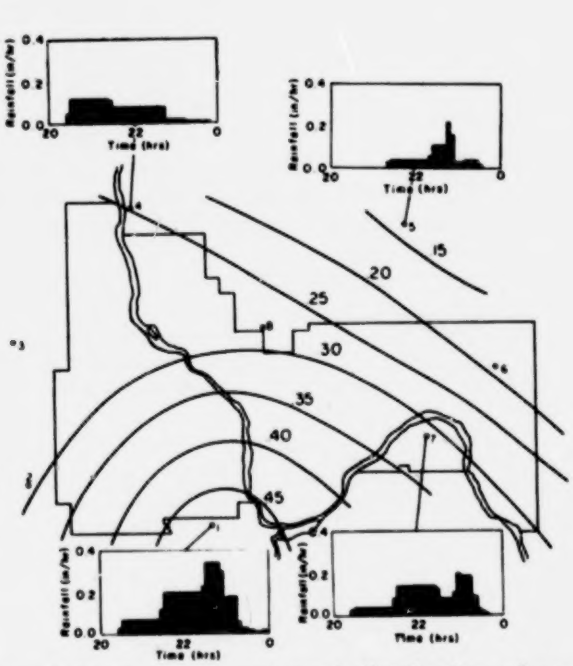
Rainfall (in/hr)
0.4
0.2
0.0
20
22
0
Time (hrs)
15
20
25
30
35
40
45

Figure 12d. Temporal and areal distribution of storm on day 267 (Sept. 24, 1969)

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The first event (day 207) was centered north of the Twin Cities. Intensities of 2 in. per hour were recorded at gage number 8. The southern-most portions of the cities received no rain at all. The significant rainfall lasted about 20 minutes. Rainfall data were recorded at about 5-minute intervals.

The second event (day 211) was centered to the west. Moderate rainfall occurred throughout the area. Intensities reached 0.8 in. per hour in most areas. The rainfall lasted about 1-1/2 hours. The rainfall data were recorded at about 5-minute intervals.

The third event (day 218) was centered to the south of the cities. Intensities as great as 3.8 in. per hour were recorded at gage number one. The northwest corner of the cities received only light showers. The significant rainfall lasted 20 minutes or less. Data were recorded at about 5-minute intervals.

The fourth event (day 267) was also centered to the south of the cities. Very mild intensities occurred over a period of three hours. Data for the early part of the storm were recorded at one-hour intervals, and therefore 5-minute intensities are shown as uniform over a one-hour period.

The effect of each of these storms on the Minnehaha inlet will be shown. This inlet is located in the southwest corner of the Twin Cities, as shown in Fig. 1. Only a portion of the sub-watershed is serviced by combined sewers contributing to the interceptor system. The area serviced is 1.14 sq mi. The farthest point in the watershed is about 3.7 mi from the interceptor inlet.

Figures 13a, b, and c show the rainfall and runoff at the Minnehaha inlet. The average precipitation and calculated excess (darkened area) is shown at the top of each figure. The computed hydrograph at the inlet before diversion and after diversion is shown at the bottom of each figure.

On day 207 no rain occurred over the southern portion of the cities. Since only sanitary base flow would appear at the Minnehaha inlet, a figure was not prepared for this day.

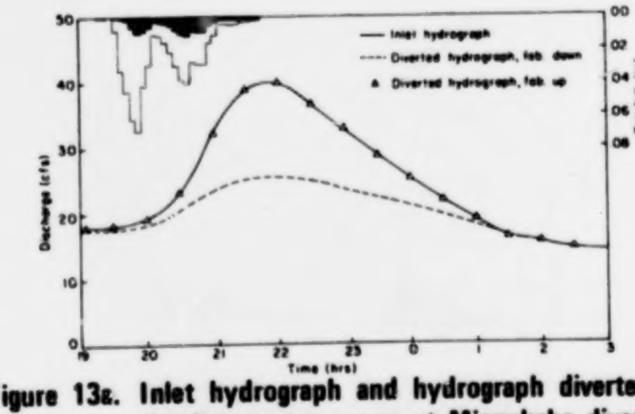

Figure 13a. **Inlet hydrograph and hydrograph diverted to the interceptor sewer at Minnehaha diversion for event of day 211.**

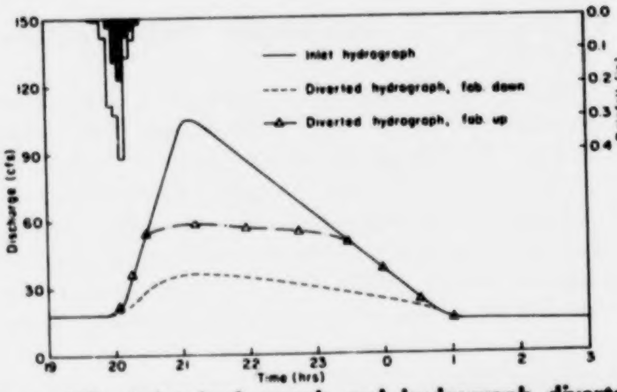

Figure 13b. **Inlet hydrograph and hydrograph diverted to the interceptor sewer at Minnehaha diversion for event of day 218.**

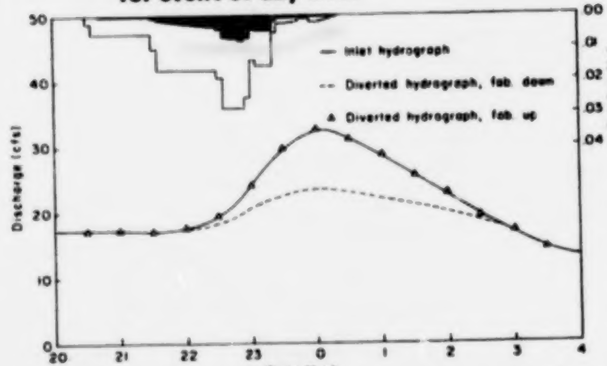

Figure 13c. **Inlet hydrograph and hydrograph diverted to the interceptor sewer at Minnehaha diversion for event of day 267.**

On day 211 (Fig. 13a) significant precipitation excess occurred in two bursts over a period of about 1 hour. All of the excess for this event came from impervious surfaces. During the storm the initial loss on the pervious surfaces was satisfied, but rainfall intensities did not exceed the computed pervious infiltration rate. In the impervious analysis the loss coefficient had been reduced to 0.44 by the end of the storm.

On day 218 (Fig. 13b) a very intense short storm occurred. In this case excess came from both pervious and impervious surfaces. The pervious contribution came during two 5 minute periods when the rainfall rate of 3.42 in/hr exceeded the infiltration rate of 1.97 in/hr giving a pervious excess of 1.46 in/hr, and the rainfall rate of 3.79 in/hr exceeded the infiltration rate of 1.83 in/hr giving a pervious excess of 1.94 in/hr. The impervious surfaces contributed excess during all periods of rainfall. At the end of the storm the impervious loss coefficient had been reduced to 0.28.

For the storm of day 267 (Fig. 13c) all the excess came from the impervious surfaces. At the end of the storm the impervious loss coefficient had been reduced to 0.50. The final pervious loss rate was 1.84 in/hr, much greater than any measured rainfall intensities.

The inlet hydrograph produced from the total excess is shown by the solid line in figures 13a, b, and

c. The precipitation excess for days 211 and 267 occurred over a period of 1-1/2 hours or more and produced hydrographs with peak discharges of 40 cfs and 33 cfs, respectively. In contrast, the large excesses for day 218 occurred in only a 10 minute period, and produced a peaked inlet hydrograph with a maximum discharge of 105 cfs.

The clipping action of the diversion structures is also seen in these figures. Two postulated conditions are shown in each figure, fabridam up and fabridam down. On days 211 and 267 (Figs. 13a and 13c) with the fabridam up, the inlet hydrograph (————) and the diverted hydrograph (Δ Δ) coincide, indicating that no flow was released to the river. On the other hand with the fabridam down (– – – –) a portion of the flow would be discharged to the river. Fig 13b (day 218) shows an inlet hydrograph with a peak discharge of 105 cfs. For this large discharge in the trunk, flow was released to the river even with the fabridam up.

The interceptor flow from the City of Minneapolis is metered at the Minneapolis-St. Paul city line. The location of the meters are shown in Figure 1. The meters are designated NW meter, SW meter, and E meter for the respective interceptor sewers they serve. The metered (————) and predicted (– – – –) discharges for the SW and E meters are shown in Figures 14a, 14b, 14c, and 14d. The NW meter is not shown because on day 211 and 218 it was found that

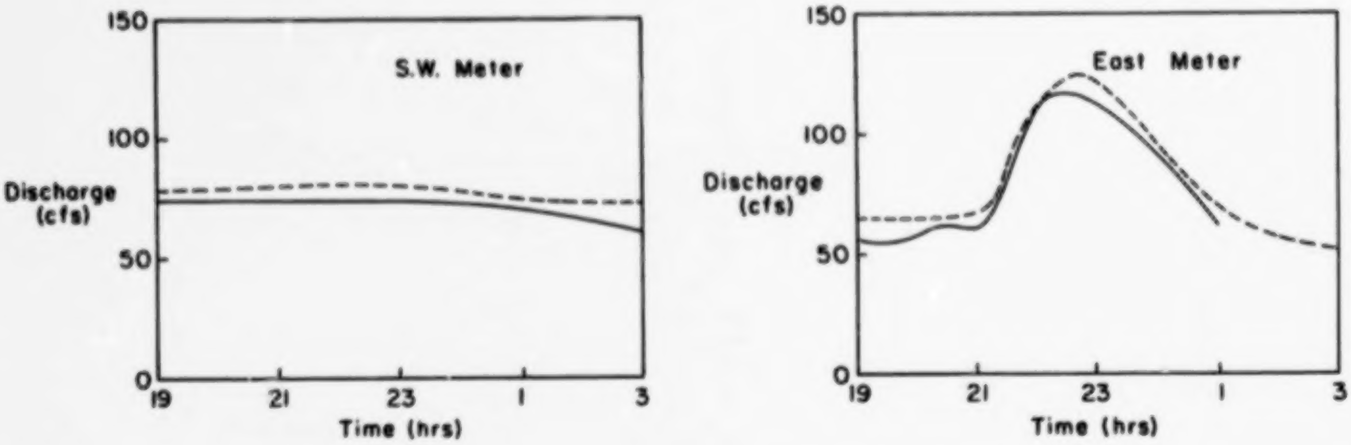

Figure 14a. Metered and model predicted flows for event of day 207.

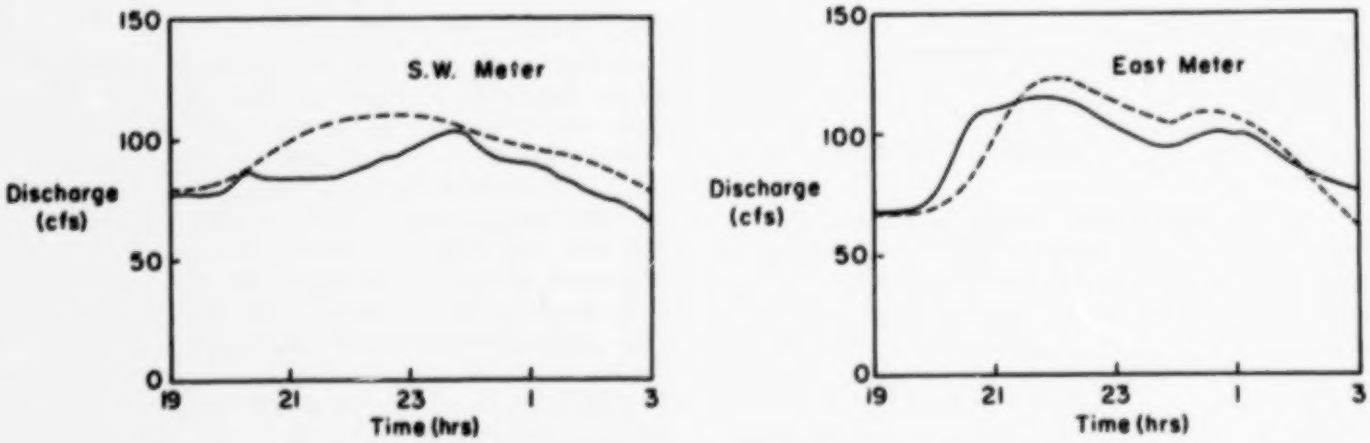

Figure 14b. Metered and model predicted flows for event of day 211.

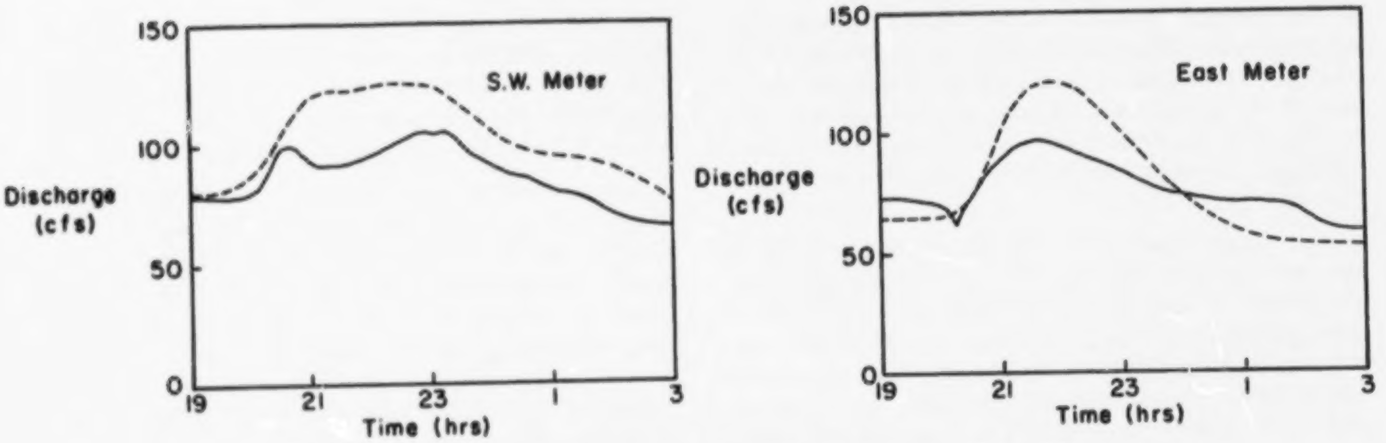

Figure 14c. Metered and model predicted flows for event of day 218.

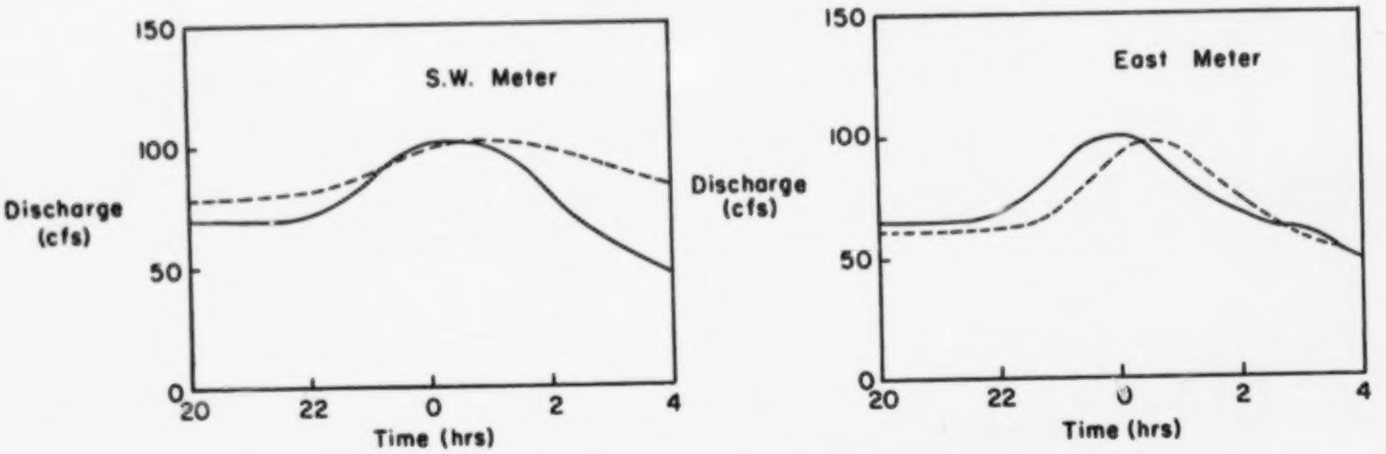

Figure 14d. Metered and model predicted flows for event of day 267.

an abnormal backwater condition affected the NW meter discharge. This condition was caused by the then unknown slippage of a gate that controls the flow of the sewage from the west side of the river to the east side. The SW meter discharges were effected by this same condition but to a lesser extent.

The results in Figures 14a, b, c, and d indicate that generally the runoff process is being modelled adequately but that further adjustment of coefficients or parameters is necessary. The results shown were obtained with only a few changes to the original values of the model parameters.

The predicted hydrograph at the headhouse (near the MSSD treatment plant) is shown in Figures 15a, b, c, and d. It is of interest to note that a numeric average over the two cities of the raingage catches are 0.52" and 0.51" for days 211 and 218 respectively. Thus, the same amount of rainfall occurring in different time and spatial patterns (see Figures 12b and 12c) produced significantly different runoff patterns and volumes. The storm for day 211 actually produced a slightly smaller volume of excess precipitation than day 218. However, for day 211 a significantly larger amount of the excess precipitation reached the interceptor and was retained in the system. This illustrates the obvious effect that the shape of the hydrograph at the diversion structure has on the amount diverted to the river. For the same volume of hydrograph much less is lost to the river if a flatter peak occurs.

In Figures 15a, b, c, and d the predicted hydrograph at the headhouse is shown for two conditions. The solid line (————) shows the expected discharge with all gates open and fabridams up. The dashed line (– – – –) shows the expected discharge with all gates open and fabridams down. For the storms on days 207, 211, 218 and 267, the percent increases of volume retained in the sewer system were 16%, 25%, 41%, and 30%, respectively. As stated earlier the lumping of some areas at major inlets increases the apparent impact of the variable diversion structures. Thus the percentages given above are probably somewhat higher than the true values, but it may be stated that there is a significant increase in the volume retained in the system when the fabridams are raised.

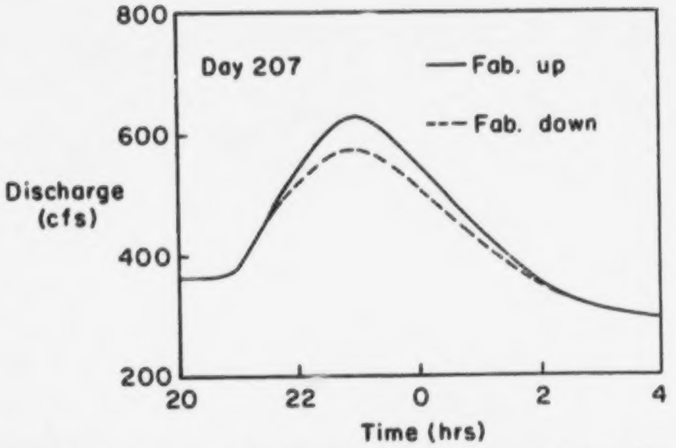

Figure 15a. Effect of fabridam on model predicted flows reaching waste treatment plant for event of day 207.

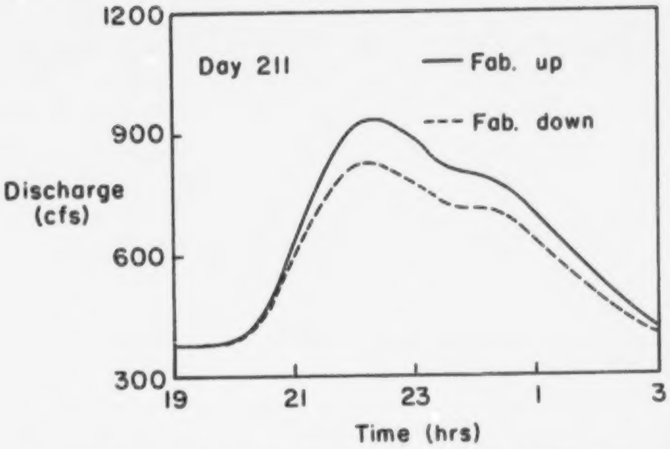

Figure 15b. Effect of fabridam on model predicted flows reaching waste treatment plant for event of day 211.

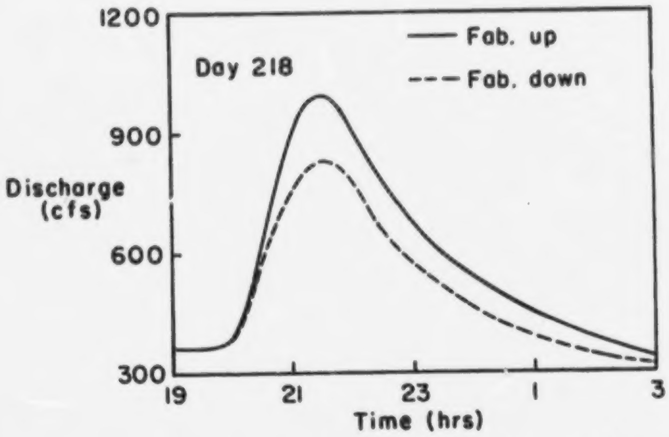

Figure 15c. Effect of fabridam on model predicted flows reaching waste treatment plant for event of day 218.

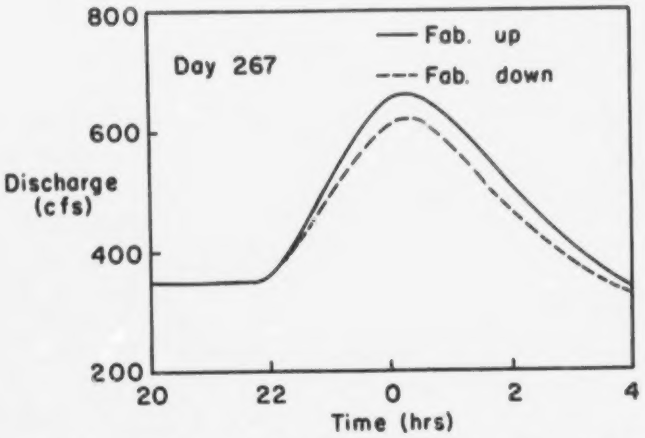

Figure 15d. Effect of fabridam on model predicted flows reaching waste treatment plant for event of day 267.

VI. CRITIQUE OF MODEL

The material in the previous sections describes the initial methods used in the model and the overall performance of these methods. Several assumptions have been made in developing the model. These assumptions will be discussed in this section and in addition suggestions for improvement of the model will be given.

1. The modeling of the diversion structures is complicated by the rubber fabridams. This device is raised and lowered pneumatically. A record is maintained of the air pressure in the fabridam. This gives an indication of the position of the fabridam which is modeled as a variable height weir. Presumably a given fabridam pressure would be associated with a given fabridam height. This is not necessarily true as water build-up behind the fabridam also causes a change in the fabridam pressure. Thus, it is difficult at best to estimate the fabridam height from the fabridam pressure. In addition the rubber fabridam is deformable. The fabridam crest is often not horizontal and may actually be depressed in a vee shape on the sides or in the center under partial inflation conditions.

2. The present spacing of the remote indicating raingages could be improved. The gages are generally spaced around the Twin City area. For modeling purposes a network centered within the area would be more desirable. Presently gage spacing averages about 5 miles, allowing significant variations in areal precipitation to go undetected.

3. The present analysis does not properly model the system for relatively large rainfall events. An urban area is actually served by two drainage systems. The primary one, the sewer system, is designed to handle a certain amount of runoff. If the runoff exceeds the capacity of the sewer system, local ponding and surface runoff will occur. This surface runoff will follow natural or man-made surface channels until it finally enters another sewer or some other surface drainage facility. In the model all runoff is assumed to enter the sewer system and arrive at the diversion structure. This is a valid assumption for small and moderate amounts of runoff (up to design values). For larger amounts where ponding and "natural diversion" occur the model will predict excessive flows in the trunks. While the diversion structures do tend to limit the flow to the interceptor there is still no upper limit on the amount they will predict that goes to the interceptor. Thus, for unreasonably large amounts of trunk flow the model will predict reasonable but still too large values of interceptor flow.

4. Each time the model is executed the initial moisture conditions in the area are taken to be zero. This would be true only when all surface depressions were dry and the upper soil moisture was at the wilting point. Actual initial conditions should be established before each real storm event. For moderate rains where only runoff from impervious areas is significant, a dry initial condition is still a reasonable assumption.

5. The use of separate pervious and impervious loss functions is desirable. Although the constants in each function have been selected by judgement only, the analysis indicates that the most significant runoff contribution in an urban area comes from the impervious area. The pervious areas contribute little runoff during the less intense rainstorms. The constants in the loss functions should be substantiated by runoff data.

6. The present model may be used for various purposes; real time operation aid, system evaluation, design evaluation, etc. As an operational tool, the accuracy and reliability of the model may be increased by the addition of a feedback correction based on measured water levels in the sewer system. The model in its existing form does not utilize the recorded water level data to aid in its prediction. This feature would be of use during real time applications. When evaluating postulated storm events, recorded data would not exist and the prediction would not include feedback correction.

7. If excessive flow is indicated in the interceptor system, the console operator must decide what gates or fabridams should be manipulated to alleviate that condition. A gate and fabridam operation scheme may be added to allow the machine to decide what the best remedy would be. The operator could still decide whether or not to implement the recommended gate or fabridam movements.

8. The addition of storage in the trunk sewer behind the fabridams or at other locations would be another desirable revision to the model. Presently storage in the trunk sewers is reflected only in the shape of the unit hydrograph. Accounting for storage in the trunk sewers would be of importance only where the storage volume is significant compared with the volume of the runoff hydrograph.

9. Only the 15 major inlets to the interceptor sewer are modeled. The flow that enters at other points in the system is assumed to contribute at the nearest major inlet. It is assumed that the additional flow lumped at the major inlets will occur in direct proportion to the relative land areas contributing. That is, if the actual area contributing to a major inlet is x sq mi, and an additional area of y sq mi is lumped at this inlet, the computed discharges based on the actual area x will be increased by the ratio $\frac{x + y}{x}$ to represent the flows from the total lumped area (x + y). This lumping correction is applied im-

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mediately following the diversion analysis at each inlet.

10. For verification and fitting purposes it is important to have recorded runoff data corresponding to given rainfall events. Presently water levels are recorded in the trunk and interceptor sewers in addition to venturi metered flows in the interceptor sewers at the Minneapolis-St. Paul city line. These recorded values are needed to assess the discharges entering or within the interceptor system. They are of less use for assessing the runoff discharges in the trunk sewers. This is due to the problem of modeling the fabridam which acts as a control section in these lines. For this reason it would be very desirable to install a fixed control section (weir) at some point in the trunk sewer that would enable the total runoff to be measured. This would allow significant improvement in the loss rate and runoff prediction.

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Appendix A

UROM-9 OPERATOR'S MANUAL

Section I – Introduction

Section II – Operation of CREATE
  1. Input data file preparation
  2. Execution of CREATE

Section III – Operation of Mathematical Model – UROM-9
  1. Input data
  2. Sense switch options
  3. Program control
  4. Gate editor
  5. Execution of model
  6. Loader Memory map of CREATE and Model (UROM-9)

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I. INTRODUCTION

UROM-9 (Urban Run-Off Model) is a digital computer program written for execution on the Minneapolis-St. Paul Sanitary District's Digital Equipment Corporation PDP-9 computer. The purpose of this program is to predict discharges in the Minneapolis-St. Paul Interceptor Sewers given rainfall readings at various points around the Twin Cities.

UROM-9 acquisitions its own data when operating on a real time basis. Instructions pertaining to the operation of the data-gathering section of UROM-9 (RTIME) are not given in this manual. References are made to RTIME only to clarify its relationship to UROM-9.

1. Method

The rain that occurs at the raingages is first operated on by a subroutine that determines rainfall losses. The excess rainfall is then applied to a unit hydrograph for each of the catchments modeled.

The resulting composite hydrograph represents the flow that would arrive at the major diversion structures of the inlets to the interceptor sewer system.

The flow then enters the interceptor. Any flow not able to pass into the interceptor is discharged to the Mississippi River. The flow entering the interceptors is increased by a lumping parameter to account for flow that does not really enter at one of the 15 major inlets modeled.

The flow in the interceptor is then routed and combined with other entering flow until it reaches the treatment plant.

2. CREATE Routine

The working section of UROM-9 requires many items of input data that describe the hydrologic, diversion and routing constants of the modeled area. These data are fixed for a given area and are handled separately from information (such as rainfall readings) that pertain to a given storm event. CREATE is a one-chain-execute file, run prior to the actual model program UROM-9, that prepares the fixed data in a form that is easily used by the model.

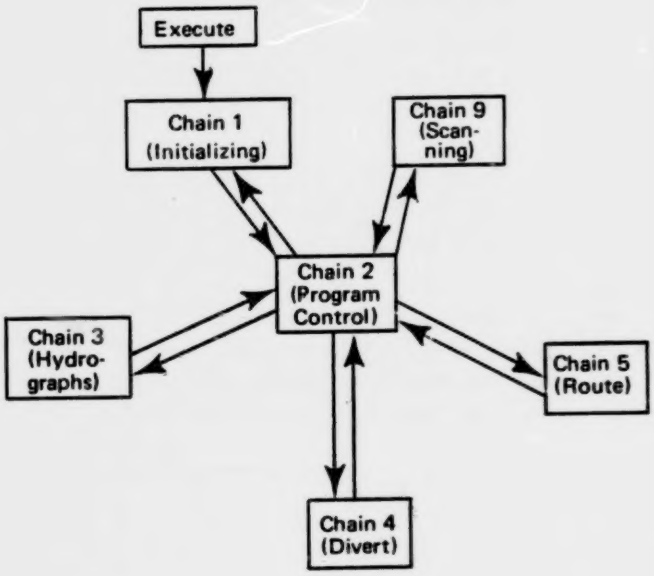
From the given input data file on the disk (DAT 3) CREATE lists the input data on the line printer (DAT 5) and then writes 4 binary output files on the disk (DAT 8). Each of these 4 binary files is used by a different chain of the model.

CREATE also does a small number of calculations. The data are not screened for errors other than those detected by the system routines.

When new input data are to be run by the model, or if old data have been changed, it is necessary to then execute CREATE before running the model. Once CREATE has been executed the model may be run any number of times.

3. Structure of Model, UROM-9

The model itself (UROM-9) is composed of 6 chains, or sections. (See Fig. 1) At any given time only one chain may be loaded into core storage. The remaining chains are held on disk storage until called by the chain in core. The data in unlabeled common storage are retained in core from chain to chain.



a. Chain 1

This chain initializes the model and is always executed first. Its functions include initializing variables and constants, loading the common storage area, setting the real time clock, setting initial loss rate parameters to zero, inputting the rainfall file to be processed, and printing instructions pertaining to sense switches used by the model. Control is always passed to Chain 2 upon completion of Chain 1.

Use of sense switches is explained in detail in III.

b. Chain 2

Chain 2 is the basic control chain for the model. After any other chain is completed, control is always passed to Chain 2. Chain 2 then determines the proper chain to be called next. This decision is based on the previous chain processed and the positions of the various sense switches selected by the operator. In addition the PROGRAM CONTROL routine within Chain 2 allows the operator to override the normal processing sequence. Use of the PROGRAM CONTROL options is explained in detail in Section 4.

If real time data acquisition is desired, the scanning chain (RTIME) (Chain 9) is called each time Chain 2 is entered. Upon completion of scanning, control is returned to Chain 2 for further model processing.

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This chain also contains the GATE EDITOR routine. This routine is explained in Section 5.

c. Chain 3

This chain begins the actual model calculations. When processing under real time conditions, initially data 2 hours prior to the current real time are used. Once this initial block is processed, Chain 3 updates the inlet hydrographs based on rainfall readings that are being acquisitioned in real time.

When historical data is being processed, processing begins at the time specified by the operator, and each prediction is updated by exactly one hour of rainfall data.

Output from Chain 3 may include the loss rate calculations and the inlet hydrographs at the 15 major inlets to the interceptor sewers.

d. Chain 4

Chain 4 performs the diversions of inlet hydrographs to determine the flow to the interceptor sewers. Fourteen of the inlet hydrographs are diverted by this chain. The 15th inlet hydrograph and the flow at 4 additional locations within the interceptors are diverted during the routing process of Chain 5.

Chain 4 always uses the hydrographs produced by the last run of Chain 3 for input data. Chain 4 may be run any number of times with different gate and Fabridam settings without re-running Chain 3.

Output from Chain 4 may include the diverted hydrographs at the major inlets, the diverted hydrographs after lumping of additional flow at the major inlets, and the volumes of the undiverted and diverted hydrographs.

e. Chain 5

Chain 5 generally performs the routing and combining operations. In addition it may divert flow at 5 points within the interceptor sewers. Its output is the interceptor flow at various locations.

f. Chain 9 (RTIME)

This chain handles the acquisition of data. It is run each time control transfers from one model chain to the next. A detailed discussion of the operation of Chain 9 is not given in this manual.

II. OPERATION OF CREATE

1. Input Data File

The input data file (INDAT8 LST, INDAT9 LST or others) resides on the disk (DAT 3). Changes to these files should be made with the system EDITOR Program. A sample listing of INDAT9 LST is given in exhibit 1. In general, the constants pertaining to hydrology are given first, then diversion, and finally routing.

Each time CREATE is executed a complete listing of input data and associated headings is given on the line printer (DAT 5). This listing, given in the next part, contains the same information that appears in the input data file, but in a different format, and includes titles and other identifying information.

When making changes to the input data a copy of the output from CREATE will aid in identifying the parameters, but an actual listing of the data file is necessary where the proper format is in question.

INDAT8 LST is the standard input data file for the 8 raingage network.

INDAT9 LST is the standard input data file for the 9 raingage network.

Exhibit 1
Sample input data file used by CREATE (INDAT9LST)

```
     9   15 300.         300.
 900.      7200.
 1800.     16200.
 830.      2230.
 900.      3300.
 3000.     10800.
 1480.      3960.
 1080.     2880.
 1200.     7800.
 3200.     18000.
 1800.     7200.
 1800.     14400.
 3600.      12000.
 2400.     10000.
 3600.      7200.
 2000.      6600.
  0.00 0.02 2.00 0.95 0.31 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.55 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.30 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.33 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.33 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.36 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.30 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.52 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.30 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.39 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.30 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.38 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.29 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.31 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
  0.00 0.02 2.00 0.95 0.33 0.70 0.20 2.00 0.00 0.00 0.25 0.00 1.00 2.00 0.00
 57200000.   3.96
 98900000.    1.06
 29600000     1.58
 136400000.   1.52
 75900000.    1.0
 49100000.    1.6
 25100000.    2.85
 53400000.    1.0
 29400000.    1.82
 36800000.    2.73
 76600000.    1.2
 31600000.    1.13
 64600000.    1.33
 61800000.    1.48
 12800000.    3.58
   1244  641
   1641 1146
   1441 1141
   1511 1646
   1144 1441
   1141 1641
   1644 1244
    641 1511
    633  633
                                                   .9         .1
 .3                                                .3         .4
 .7
                                                              .3
 0.0       0.3                                                .7

 0.1       0.4                                                .5

 0.0       1.0
 .2
 0.0       0.8

 0.4       0.6

 0.6       0.4

 0.2       0.1                 .7
 .2        .3
 0.0       0.5
 1.
```

```
.00          .05          .05
0.0          0.9
                          .5
0.0          0.5
                          .0          1.0

PHALN
TROUT
KELLO
RICE
MARSH
EUSTI
OAK
RANDO
38TH
MINNE
26TH
6TH
42ND
2ND
EASTM
NW   M
SW   M
      1     2     4     5     6     8     9    10    11    12    13    14    15   200
    200   200   200     7     3
      0     0    94     0     0     0     0    18     0     0     0     0     0   209
    168   272   242    30    40
      3     1     0     2     1     0     1     0     1     1     1     1     0     1
      0     0     0
3.          3.          3.3         3.          3.          3.          3.
0.          3.          3.          3.          3.          4.1         3.
0.6         0.6         0.6
.026        .026        3.          .026        .026        1.5         .026
0.          .026        .026        .026        .026        28.5        .026
6.          6.          6.
1.5         1.5         .6          1.5         1.5         .178        1.5
0.          1.5         1.5         1.5         1.5         .6          1.5
0.          0.          0.
2.5         2.7         3.          3.          3.          0.          2.750
0.          3.          2.75        4.          8.          4.          4.
0.          0.          0.
-1.7        -2.55       0.          -6.5        -0.7        0.          0.
0.          0.          0.          0.          -0.6        0.          0.
0.          0.          0.
1.5         5.5         9.5         4.1         4.25        0.6         6.
1.7         9.25        2.5
9.67        10.         5.7         8.          9.75        7.5         8.0
0.          10.         10.5        8.          7.5         0.          7.
0.          0.          9.          5.          0.
    48
     4    15          15                          10.0    42N-1
     1    15          15     2   -11    25        150.    4TNBI
     1    15          15     2     1     3        250.    6THWA
     2    15    14    15                         3290.    6THWA
     3    15     0    15    12     1     0       0290.    6THWA
     1    15          15     6    -7     6       4290.    26SEA
     2    15    13    15                         5360.    26SEA
     1    15          15     2     0     1       6360.    NWMET
     4    12          12                          20.0    MINWI
     1    12          12     6   -24    10        770.    38TH
     2    12    11    12                         8165.    38TH
     1    12          12     8    -1     2       9165.    SWMET
     3    12          12    17     7     1      10165.    SWMED
     3    15          15    16     7     2      11360.    NWMED
     2    15    12    15                        12530.    METCO
     1    15          15     2     1     1      13530.    METUN
     4    10          10                           5.0    HALFI
     1    10          10     6   -10    12       1460.    2NDMA
     3    10          10    14     1             1560.    2NDMA
     1    10          10     6    -4     5       1660.    OAK
     2    10     9    10                        17125.    OAK
     1    10          10    15     1     1      18125.    EMET
     3    10          10    15     7     3      19125.    EMETD
     1    10          10     6     0     2      20125.    EUSEI
     2    10     8    10                        21200.    EUSEI
     1    10          10     3     0     2      22200.    MEJUN
     2    15    10    15                        23600.    MEJUC
     1    15          15     2     0     1      24600.    MRBJN
     4     7           7                                  JEFFI
     1     7           7     5     1     2      2519.3     MARSH
     2     7     6     7                         2690.    MARSH
     1     7           7     2     1     1       2790.    MRBJN
     2    15     7    15                        28690.    MRBJC
     1    15          15     2   -10   120      29690.    RICE
     2    15     5    15                        30690.    RICE
     1    15          15     2     1     1      31690.    WABEN
     4     4           4                                  KELOI
     1     4           4     2     1     1       3270.    WABJN
     4     3           3                                  DAWNI
     1     3           3     4   -14     6       3355.    WABJN
     2     3     4     4                        34170.    WABJC
     1     4           4     3     0     3      35170.    WABEN
     2    15     4    15                        36820.    WABEC
     1    15          15     8     1     1      37820.    INTTR
     2    15     2    15                        38820.    INTTC
     1    15          15     2     1     1      39820.    INTPH
     2    15     1    15                        40900.    INTPC
     1    15          15     8     1     1      41900.    INTMH
 5.97         0.00073     0.012
 9.66         0.0007      0.012
 5.97         0.00095     0.012
 6.7          16.0        3.8         6.1         8.9         3.1         3.8
 22.4         11.5        10.2        16.0        32.0        14.5        24.0
 5.8
 1.02         0.98        0.93        0.88        0.83        0.79        0.74
 0.70         0.69        0.73        0.82        0.94        1.05        1.14
 1.20         1.23        1.25        1.26        1.24        1.28        1.15
 1.11         1.08        1.04
   46  44  39  37  34  30  29  24  20  17  10   9   6   3   1
```

2. Execution of CREATE

CREATE is an execute file that normally resides on the disk unit. It is run from the system monitor by the command

$E CREATE ↲

(where ↲ indicates a carriage return).

The message then appears on the console;

ENTER NAME OF INPUT DATA FILE

one of the input data file names should then be typed by the operator as,

INDAT9 LST ↲

If the name given by the operator is valid the following message appears, otherwise another file name is requested.

ENTER TIME AND DATE (15AS)

The time, date, and any other information may then be entered on one line. Whatever is entered appears on the Line Printer listing for identification purposes.

Upon completion the following appears on the console:

STOP 000000

and control then returns to the system monitor.

An example of an execution of CREATE is shown in exhibits 2 and 3.

Exhibit 2
Sample teletype output from CREATE

```
MONITOR V4B

$E CREATE

ENTER NAME OF INPUT DATA FILE

RA

ENTER NAME OF INPUT DATA FILE

INDAT9 LST

ENTER NAME OF INPUT DATA FILE

INDAT9LST

ENTER TIME AND DATE (15A5)

 12:42 OCT 8,1970

STOP  000000
```

Exhibit 3
Sample line printer output from CREATE

```
12:42 OCT 8,1970
INPUT DATA FILE USED - INDAT9LST

NO OF GAUGES    9
NO OF CACHMENTS  15
TIME INCREMENT OF RAINFALL READINGS       300. SECS
TIME INCREMENT OF HYDROGRAPHS       180. SECS

TIME TO PEAK     BASE TIME     CACH.NO
  900.            7200.           1
 1600.           16200.           2
  830.            2230.           3
  900.            3300.           4
 1000.           10800.           5
 1480.            3960.           6
 1060.            2880.           7
 1700.            7600.           8
 3200.           18000.           9
 1860.            7200.          10
 1800.           14400.          11
 3600.           12000.          12
 2400.           10000.          13
 3600.            7200.          14
 2000.            6600.          15

LOSS RATE VARIABLES
NO. TSILOS RECOV AK DECAY PERV PIRVCF SNOW TBPC BMC SFLOS ISTLOSP STLOSP COEF POWER ACCLOSS

   1    0.00    0.02    2.00    0.95    0.31    0.70    0.70    2.00    0.00    0.00    0.25    0.00    1.00    2.00    0.00
   2    0.00    0.02    2.00    0.95    0.35    0.70    0.20    2.00    0.00    0.00    0.25    0.00    1.00    2.00    0.00
   3    0.00    0.02    2.00    0.95    0.30    0.70    0.20    2.00    0.00    0.00    0.25    0.00    1.00    2.00    0.00
   4    0.00    0.02    2.00    0.95    0.31    0.70    0.20    2.00    0.00    0.00    0.25    0.00    1.00    2.00    0.00
   5    0.00    0.02    2.00    0.95    0.31    0.70    0.20    2.00    0.00    0.00    0.25    0.00    1.00    2.00    0.00
 6   0.00   0.02   2.00   0.95   0.36   0.70   0.20   2.30   0.00   0.00   0.25   0.00   1.00   2.00   0.00
 7   0.00   0.02   2.00   0.95   0.30   0.70   0.20   2.30   0.00   0.00   0.25   0.00   1.00   2.00   0.00
 8   0.00   0.02   2.00   0.95   0.52   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
 9   0.00   0.02   2.00   0.95   0.10   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
10   0.00   0.02   2.00   0.95   0.19   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
11   0.00   0.02   2.00   0.95   0.10   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
12   0.00   0.02   2.00   0.95   0.38   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
13   0.00   0.02   2.00   0.95   0.29   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
14   0.00   0.02   2.00   0.95   0.31   0.70   0.20   2.90   0.00   0.00   0.25   0.00   1.00   2.00   0.00
15   0.00   0.02   2.00   0.95   0.33   0.70   0.20   2.00   0.00   0.00   0.25   0.00   1.00   2.00   0.00
AREAS(SQ FT)    FACTORS    CACH.NO
  57199488.           1.96      1
  98899488.           1.06      2
  29599744.           1.58      3
1136400000.           1.52      4
  75899488.           1.00      5
  69099744.           1.60      6
  25099872.           2.85      7
  53399744.           1.00      8
  29399744.           1.82      9
  36799744.           2.73     10
  76599488.           1.20     11
  31599744.           1.13     12
  64599488.           1.33     13
  61799488.           1.48     14
  12799936.           3.58     15

RAINGAGE ADDRESSES IN ORDER USED BY MODEL AND SCANNED

      1   1244    641
      2   1641   1144
      3   1441   1141
      4   1511   1644
      5   1144   1441
      6   1141   1641
      7   1644   1244
      8    641   1511
      9    633    633

RAIN GAUGE PROPORTIONS
GAUGE NO  1      2         3         4         5         6         7         8         9
       0.000    0.000     0.000     0.000     0.000     0.900     0.100     0.000     0.000     1
       0.000    0.000     0.000     0.000     0.000     0.100     0.400     0.100     0.300     2
       0.700    0.000     0.000     0.000     0.000     0.000     0.300     0.000     0.000     3
       0.000    0.000     0.000     0.000     0.000     0.000     0.700     0.600     0.300     4
       0.000    0.000     0.000     0.000     0.000     0.000     0.500     0.100     0.400     5
       0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.000     1.000     6
       0.200    0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.800     7
       0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.400     0.600     8
       0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.600     0.400     9
       0.000    0.000     0.000     0.700     0.000     0.000     0.000     0.200     0.100    10
       0.200    0.300     0.000     0.000     0.000     0.000     0.000     0.000     0.500    11
       1.000    0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000    12
       0.000    0.050     0.050     0.000     0.000     0.000     0.000     0.000     0.900    13
       0.000    0.000     0.500     0.000     0.000     0.000     0.000     0.000     0.500    14
       0.000    0.000     0.000     1.000     0.000     0.000     0.000     0.000     0.000    15
 HYDROGRAPH NO AND DIVERSION NO
    1     1
    2     2
    4     3
    5     4
    6     5
    8     6
    9     7
   10     8
   11     9
   12    10
   13    11
   14    12
   15    13
  200    14
  200    15
  200    16
  200    17
    7    18
    3    19

  INDEX OF DIVERSION POINT
     0    1
     0    2
    96    3
     0    4
     0    5
     0    6
     0    7
    18    8
     0    9
     0   10
     0   11
     0   12
     0   13
   209   14
   168   15
   272   16
   242   17
    30   18
    40   19
```

```
ORIFICE TYPE
      3    1
      1    2
      0    3
      2    4
      1    5
      0    6
      1    7
      0    8
      1    9
      1   10
      1   11
      1   12
      0   13
      1   14
      0   15
      0   16
      0   17
            C1          C2          C3          C4          C5          C6          C7          C8          C9          C10         C11         C12
      1   2.99998     0.02600     1.49999     2.49997    -1.69998
      2   2.99998     0.02600     1.49999     2.69998    -2.54997
      3   3.29998     2.99998     0.60000     2.99998     0.00000
      4   2.99998     0.02600     1.49999     2.99998    -5.49993
      5   2.99998     0.02600     1.49999     2.99998    -0.70000
      6   2.99998     1.49998     0.17800     0.00000     0.00000
      7   2.99998     0.02600     1.49999     2.74995     0.00000
      8   0.00000     0.00000     0.00000     0.00000     0.00000
      9   2.99998     0.02600     1.49999     2.99998     0.00000
     10   2.99998     0.02600     1.49999     2.74995     0.00000
     11   2.99998     0.02600     1.49999     3.99995     0.00000
     12   2.99998     0.02600     1.49999     7.94990    -0.60000
     13   4.09996    28.49957     0.60000     3.99995     0.00000
     14   2.99998     0.02600     1.49999     3.99995     0.00000
     15   0.60000     5.99996     0.00000     0.00000     0.00000
     16   0.60000     5.99996     0.00000     0.00000     0.00000
     17   0.60000     5.99993     0.00000     0.00000     0.00000
                                                                    1.49999     5.49990     9.49990     4.09996     4.26996     0.60000     5.99996
C13   1.69999        C14    9.24984 C15    2.49997

FABRIDAM DIAMETERS
    1    9.66990
    2    9.99984
    3    5.69996
    4    7.99990
    5    9.74984
    6    7.49990
    7    7.99990
    8    0.00000
    9    9.99984
   10   10.49984
   11    7.99990
   12    7.49990
   13    0.00000
   14    6.99990
   15    0.00000
   16    0.00000
   17    0.00000
UPERATION TABLE.HYDROGRAPH NOS AND ROUTING CONSTS
 OPER     HYD ENTER HYD  COMB HYD LEAVE   NSTRL       LAG          NRCHS  QMAX
        1        4       15        0       15        0       0          0      10.042N-I
        2        1       15        0       15        2     -11         25      50.04THNI
        3        1       15        0       15        2       1          3      50.06THWA
        4        2       15       14       15        0       0          0     270.06THWA
        5        3       15        0       15       12       1          0     290.06THWA
        6        1       15        0       15        6      -7          6     290.026SEA
        7        2       15       13       15        0       0          0     360.026SEA
        8        1       15        0       15        2       0          1     360.0NWMET
        9        4       12        0       12        0       0          0      20.0MINHI
       10        1       12        0       12        9     -24         10      70.038TH
       11        2       12       11       12        0       0          0     165.038TH
       12        1       12        0       12        8      -1          2     165.0SWMET
       13        3       12        0       12       17       7          1     165.0SWMED
       14        3       15        0       15       16       7          2     360.0NWMED
       15        2       15       12       15        0       0          0     530.0METCO
       16        1       15        0       15        2       1          1     530.0METUN
       17        4       10        0       10        0       0          0       5.0RNLFI
       18        1       10        0       10        6     -10         12      60.02NDMA
       19        3       10        0       10       14       1          0      60.02NDMA
       20        1       10        0       10        6      -4          5      60.0DAK
       21        2       10        9       10        0       0          0     125.0DAK
       22        1       10        0       10       15       1          1     125.0EMET
       23        3       10        0       10       15       7          3     125.0EMETD
       24        1       10        0       10        6       0          2     125.0EUSTI
       25        2       10        8       10        0       0          0     200.0EUSTI
       26        1       10        0       10        3       0          2     200.0MEJUN
       27        2       15       13       15        0       0          0     600.0MEJUC
       28        1       15        0       15        2       0          1     600.0MRBJN
       29        4        7        0        7        0       0          0       0.0JEFFI
       30        1        7        0        7        5       1          2      19.3 MARS
       31        2        7        6        7        0       0          0      90.0MARSH
       32        1        7        0        7        2       1          1      90.0MRBJN
       33        2       15        7       15        0       0          0     690.0MRBJC
       34        1       15        3       15        2     -10        120     690.0RICE
       35        2       15        5       15        0       0          0     690.0RICE
       36        1       15        3       15        2       1          1     690.0WABIN
       37        4        4        0        4        0       0          0       0.0KELUI
       38        1        4        0        4        2       1          1      70.0WABJN
       39        4        3        0        3        0       0          0       0.0DAVNI
       40        1        3        0        3        4     -14          6      55.0WABJN
       41        2        3        4        4        0       0          0     170.0WABJC
       42        1        4        0        4        3       0          3     170.0WABIN
       43        2       15        4       15        0       0          0     820.0WABIC
       44        1       15        0       15        8       1          1     820.0INTTR
       45        2       15        2       15        0       0          0     820.0INTTC
       46        1       15        0       15        2       1          1     820.0INTPH
       47        2       15        1       15        0       0          0     900.0INTPC
       48        1       15        0       15        8       1          1     900.0INTHH
```

```
                DIAM =        5.97  SLOPE =    0.00073 MANNINGS N =      0.012
                DIAM =        9.66  SLOPE =    0.00070 MANNINGS N =      0.012

                DIAM =        5.97  SLOPE =    0.00095 MANNINGS N =      0.012

BASE FLOW
   1         6.7
   2        16.0
   3         3.8
   4         6.1
   5         8.9
   6         3.1
   7         3.8
   8        22.4
   9        11.5
  10        10.2
  11        16.0
  12        32.0
  13        14.5
  14        24.0
  15         5.8

      HOURLY BASE FLOW FACTORS

           1  1.02
           2  0.98
           3  0.93
           4  0.88
           5  0.83
           6  0.79
           7  0.74
           8  0.70
           9  0.69
          10  0.73
          11  0.82
          12  0.94
          13  1.05
          14  1.14
          15  1.20
          16  1.23
          17  1.25
          18  1.26
          19  1.24
          20  1.20
          21  1.15
          22  1.11
          23  1.08
          24  1.04

 NAME  INDEX
    1    46
    2    44
    3    39
    4    37
    5    34
    6    30
    7    29
    8    24
    9    20
   10    17
   11    10
   12     9
   13     6
   14     3
   15     1
 ITP      3     6     3     3    10     5     4     4    11     6     6    12     8    12     7
 ITB     24    54     7    11    36    13    10    26    60    24    48    40    33    24    22
```

III. OPERATION OF MATHEMATICAL MODEL–UROM-9

1. Input Data

All input data that are fixed for all events are processed by CREATE as explained in Section I. These data are prepared as 4 binary files. The first file (STARTLIST) is used by Chain 1 to initialize the model. The remaining files, HYDROLIST, DIVERLIST, ROUTELIST, are used by Chains 3, 4, and 5 respectively.

In addition to the fixed data the model also requires input data consisting of the rainfall at the remote gages, the gate and Fabridam settings to be used, and the initial moisture conditions before the storm.

When processing real time data the model uses the file RAINRP DLY to obtain its rainfall data. New data are continually being added to this file by chain 9 (RTIME).

When historical data are being processed, rainfall data are obtained from any file specified by the operator. If new real time rainfall data will also be acquisitioned, they will be put in the file RAINRP DLY.

The gate and Fabridam settings that the model will use are stored in a file GATESETTG. This file contains the times and positions of gates and Fabridams, as well as the maximum and minimum values allowable. All positions are in feet. This file may be changed by the GATE EDITOR routine (part of the model) or by the systems EDITOR program.

The current values of basin moisture and starting loss are found in the file BMCXSTLOS. This file contains for each of the 15 major catchments, the Basin Moisture Content (BMC) and the starting loss (STLOSP) for the pervious areas and accumulated loss (ACLOSS) and starting loss (STLOS) for the impervious areas. These are given in inches. The last entry of the file is the accumulated time in seconds since the DECAY (a recovery factor) has been applied to update the moisture values.

2. Sense Switch Options

Accumulator switches located on the lower right side of the central processor are used as sense switches by the model. All sense switches should be off (down) at the beginning of execution of the model unless the operator is familiar with the program. The use of each sense switch is described below.

Sense Switch Number

# 0	Not presently used
# 1	Normally if all sense switches are down the only printed output on the line printer will be a message indicating when the model predicts that there will be excessive flow at a given point. If this switch is up this message will not be printed.
# 2	If this switch is up the model will return to "Program Control" if excessive flow is predicted anywhere in the system. This then allows the operator to postulate possible corrective changes or to continue calculations as he desires.
# 3	If it is desired to see the rainfall rates at the raingages for each 5-minute period, the rainfall rates over each catchment, the loss rates, basin moisture content, and the rainfall excess, this switch should be up.
# 4	If on, this switch allows the latest inlet hydrograph for each major watershed to be printed. These represent the flow arriving at the structure before diversion.
# 5	If on, the diverted hydrographs for each major watershed and the total lumped flow entering the interceptor sewers will be printed.
# 6	If on, a tabulation of the volumes of water before diversion, after diversion, and diverted to the river will be shown.
# 7	If on, the hydrograph at any point in the interceptor system where the predicted flow is greater than the allowable flow will be printed.
# 8	If on, all hydrographs will be printed as the flow is routed through the interceptor system.
# 9	If on, only the inlet hydrographs before diversion will be computed. Model will cycle through chains 1, 2, 3, and 6 only (no diversion or routing).
#10	If on, only the inlet hydrographs and diverted hydrographs will be computed. Model will cycle through chains 1, 2, 3, 4, and 6 (no routing).
#11	Not presently used.
#12	If on, the program will scan real time data only (RTIME).
#13	If on, the program will not scan any real time data.
#14	If on, the program will interrupt its normal processing and return to program control for operator intervention. The computations interrupted will be lost.
#15	If on, the program will process a historical rainfall file specified by the operator. The data will be processed in one-hour blocks, starting at the time given by the operator.
#16	If on, the instructions normally printed out on the teletype will not appear.
#17	If on, the program will return to program control for operator intervention after completing the chain of the model that it is currently working on. No computations will be lost.

The sense switches may be reset at any time. Depending on the specific function of the switch it may have an immediate effect on the program or a delayed effect. When controlling or interrupting the sequence of processing by switches #9, #10, #14, or #17, the operator must be careful to re-enter the processing sequence at the proper point.

3. Program Control

The model is so constructed that an operator may intervene in the normal processing sequence. This is accomplished by the routine PROGRAM CONTROL.

At any time during processing the operator may turn on sense switch (SS) #14 or #17 to return to PROGRAM CONTROL.

PROGRAM CONTROL is also entered at other times when information is needed by the program.

The options within PROGRAM CONTROL available to the operator are given below.

#1. The model is reentered at its origin. This gives the operator a chance to process a new historical rainfall file or to process real rainfall in file RAINRP DLY. Control is transfered to Chain 1.

#2. This allows the operator to restart computing inlet hydrographs. When processing real data the program always computes starting 2 hours prior to the present real time or at the beginning of the RAINRP DLY file, whichever is later. For a historical file the model starts at the starting time given by the operator. This time is entered by the operator at the console. If rain has occurred prior to the starting time given by the operator, the first two hours of prediction will not reflect this rain. Control is transfered to Chain 3.

#3. This causes the model to continue the processing by adding on the latest rainfall readings for real time data or readings for one hour for historical data. Control is transfered to Chain 3.

#4. When reentering at this point the program takes the last determined inlet hydrographs and diverts them. Control is transfered to Chain 4.

#5. When reentering at this point the program takes the last determined diverted hydrographs and routes them. Control is transfered to Chain 5.

#6. This allows the program to scan if it is the proper time. PROGRAM CONTROL will always be reentered following this selection unless sense switch #12 is kept on. Control is transfered to Chain 9.

#7. This calls the gate editor program. The gate editor allows the operator to enter gate settings to the model.

#8. This causes the program to stop and return control to the monitor.

4. Gate Editor

The GATE EDITOR is an option called from PROGRAM CONTROL that allows the operator to delete, insert or replace gate and Fabridam settings that are used by the model. The file that contains the model gate settings is GATESETTG. If desired this file may be changed with the systems EDITOR program, but this requires that the model be stopped.

The GATE EDITOR has 5 operations, explained below.

1. The first operation (L) provides a listing of all the gate and Fabridam settings. In addition the maximum and minimum settings for each structure are shown.
2. This operation (D) will delete a setting from the file. The settings for day zero and day 365 may not be deleted.
3. This operation (I) will insert a new setting.
4. This operation (R) will replace a given setting with a new value.
5. This operation (E) causes the routine to return to PROGRAM CONTROL.

Format:

N GT HR MN DAY X.XX X.XX

where

N	is operation to be completed (L, D, I, R, E)
GT	is gate number
HR	is hour of day (0-23)
MN	is minute of hour (0-59)
DAY	is day of year (1-364)
X.XX	is gate opening in feet
X.XX	is fabridam height in feet

Exhibit 4 shows the teletype message when GATE EDITOR is used.

Exhibit 4

Teletype message when Gate Editor is used.

```
GATE EDITOR

TYPE L FOR LISTING OF PRESENT GATESETTINGS
TYPE D WITH GATE NUMBER AND TIME- TO DELETE A SETTING
TYPE I WITH GATE NUMBER, TIME AND SETTING- TO INSERT SETTING
TYPE R WITH GATE NUMBER, TIME AND SETING- TO REPLACE SETTING
TYPE E TO EXIT TO PROGRAM CONTROL

N GT HR MN DAY X.XX X.XX

L
N GT HR MN DAY X.XX X.XX

E
```

Exhibit 5 shows the list of gate and Fabridam settings.

Exhibit 5.
List of gate and Fabridam settings.

```
                    GATE AND FABRIDAM SETTINGS

DIVERSION          TIME            GATE     FABRIDAM    MAX       MAX
 NUMBER       HR   HMN   DAY     SETTING    SETTING    GATE    FABRIDAM

  0            0    0      0      0.00       0.00      0.00      0.00
  1  PHAL      0    0      0      2.50       3.00      2.50      6.25
  1  PHAL      0    0    365      2.50       6.25      2.50      6.25
  2  TROUT     0    0      0      1.75       1.67      1.75      7.00
  2  TROUT     0    0    365      1.75       7.00      1.75      7.00
  3  KELOG     0    1      0      6.00       1.25      6.00      4.67
  3  KELOG     0    0    365      6.00       4.67      6.00      4.67
  4  RICE      0    0      0      3.00       1.00      3.00      5.50
  4  RICE      0    0    365      3.00       5.50      3.00      5.50
  5  MARSH     0    1      0      3.75       1.67      3.75      6.00
  5  MARSH     0    0    365      3.75       6.00      3.75      6.00
  6  EUSTE     0    0      0      3.00       1.50      3.00      5.67
  6  EUSTE     0    0    365      3.00       5.67      3.00      5.67
  7  OAK       0    0      0      1.25       3.00      1.25      5.33
  7  OAK       0    0    365      1.25       5.33      1.25      5.33
  9  38TH      0    0      0      1.25       2.50      1.25      6.67
  9  38TH      0    0    365      1.25       6.67      1.25      6.67
 10  MINNH     0    0      0      1.25       3.50      1.25      6.82
 10  MINNH     0    0    365      1.25       6.82      1.25      6.82
 11  26SEA     0    0      0      2.10       2.00      2.10      5.33
 11  26SEA     0    0    365      2.10       5.33      2.10      5.33
 12  PWASH     0    0      0      2.10       3.12      2.10      5.67
 12  PWASH     0    0    365      2.10       5.67      2.10      5.67
 13  42CAM     0    0      0      4.00       0.00      4.00      0.00
 13  42CAM     0    0    365      4.00       0.00      4.00      0.00
 14  2MAIN     0    0      0      2.10       2.16      2.10      4.67
 14  2MAIN     0    0    365      2.10       4.67      2.10      4.67
 15  NWM       0    0      0      0.00       0.00      0.00      0.00
 15  NWM       0    0    365      0.00       0.00      0.00      0.00
 16  SWM       0    0      0      0.00       0.00      0.00      0.00
 16  SWM       0    0    365      0.00       0.00      0.00      0.00
 17  EASTM     0    0      0      0.00       0.00      0.00      0.00
 17  EASTM     0    0    365      0.00       0.00      0.00      0.00
 18  EUSTW     0    0      0      3.00       1.50      3.00      3.50
 18  EUSTW     0    0    365      3.00       3.50      3.00      3.50
 19  42-BP     0    0      0      0.00       0.00      0.00      0.00
 19  42-BP     0    0    365      0.00       0.00      0.00      0.00
```

5. Execution of Model (UROM-9)

MODEL is an execute file that normally resides on the disk. It is run from the system monitor by the command:

```
$E MODEL
```

The processing that follows depends on the selection of the various sense switches. As noted above all sense switches (accumulator switches are used as sense switches and are located on the lower right side of the central processor) should be down (off) at the beginning of execution unless the operator is familiar with the program. When the sense switches are down the program will print out important instructions at all points where the operator may interact with the program.

The following message will appear to inform the operator of the possible choices he has available for output and program branching.

The MODEL may be used in any of the following modes:

a. Gather real time data only

b. Gather real time data and process real time data

c. Gather real time data and process historical data

d. Process historical data only

A description of each of these modes follows.

a. To use the model to acquisition data only, SS #12 should be turned on. The operator will be requested to ENTER REAL TIME. Then control will pass to Chain 9 and will remain there as long as SS #12 is on.

b. To both gather and process real time data SS #12 and #13 should be off. The operator will be requested to ENTER REAL TIME. Then control will pass to Chain 9 to allow data acquisition and on to Chain 3 to allow data processing.

c. To gather real time data and process historical data SS #12 and #13 should be off and SS #15 should be on. The operator will be requested to enter the name of the historical rainfall file to be processed.

```
ENTER NAME OF HISTORICAL RAINFALL FILE
              (FILNAMEXT)
```

At this point the operator should type the 9 character file name containing the rain data to be processed followed by a carriage return. If the file is not present on the input device (DAT. 10) an error will appear:

```
FILE XXXXXXXXX NOT PRESENT ON DEVICE 8
```

and the operator will have the opportunity of entering another file name.

After allowing a scan to occur in Chain 9 control will return to PROGRAM CONTROL. At this time the operator should exercise option 2. This will allow him to then ENTER MODEL STARTING TIME. Processing will then be initiated at the specified time in the historical rainfall file.

d. To process historical data only, the procedure outlined in 3 should be followed except that SS #13 should be on.

When acquisitioning data the scanning reports will appear on the line printer. Output from the model will appear depending on the settings of the sense switches.

Exhibit 6 shows the teletype output for a run made using an historical rainfall file (RASR70219). After processing two hours of data the operator interrupted the program, made a listing of the gate and Fabridam settings and returned to the system monitor. Exhibit 7 shows part of the rainfall data used.

Exhibit 6
Teletype output for sample model run.

```
MONITOR V40

$E MODEL

SENSE SWITCHES(ACCUM. SWS) #1-[redacted]17 ARE USED IN THIS PROGRAM
 IF ON(UP) THEY HAVE THE FOLLOWING FUNCTIONS

 #1 SURPRESS PRINTOUT OF EXCESSIVE FLOW LOCATIONS
 #2 PAUSE IF EXCESSIVE FLOW
 #3 PRINTOUT RAINFALL LOSS-RATE DATA
 #4 PRINTOUT UNDIVERTED HYDROGRAPHS
 #5 PRINTOUT DIVERTED HYDROGRAPHS
 #6 PRINTOUT VOLUMES OF HYDROGRAPHS
 #7 PRINTOUT HYDROGRAPHS AT POINTS OF EXCESSIVE FLOW
 #8 PRINTOUT HYDROGRAPHS AT ALL POINTS
 #9 COMPUTE UNDIVERTED HYDROGRAPHS ONLY
 #10 COMPUTE UNDIVERTED AND DIVERTED HYDROGRAPHS ONLY
 #12 SCAN REAL TIME DATA ONLY
 #13 DO NOT SCAN REAL TIME DATA
 #14 RETURN TO PROGRAM CONTROL
 #15 PROCESS HISTORICAL RAINFALL FILE
 #16 SUPPRESS PRINTOUT OF PROGRAM INSTRUCTIONS
 #17 PAUSE AT END OF LATEST COMPUTATIONS

SET SWITCHES TO DESIRED POSITION AND THEN TYPE
CONTROL P  AFTER THE PAUSE
THE SWITCHES MAY BE RESET AT ANY TIME

PAUSE 000000
*PENTER NAME OF HISTORICAL RAINFALL FILE (FILNAMEXT)

 RASR70 219

     FILE  RASR70 21  NOT PRESENT ON DEVICE 8

  ENTER NAME OF HISTORICAL RAINFALL FILE (FILNAMEXT)

 RASR70219

 ENTER REAL TIME
  HR MN DAY

  12 12 201

 PROGRAM CONTROL PREVIOUS CHAIN   1  MODEL TIME  201 12 12

 TYPE 1 TO RESTART WITH ALL INITIAL CONDITIONS
 TYPE 2 TO RESTART COMPUTING UNDIVERTED HYDROGRAPHS
 TYPE 3 TO CONTINUE COMPUTING UNDIVERTED HYDROGRAPHS
 TYPE 4 TO CONTINUE COMPUTING DIVERTED HYDROGRAPHS
 TYPE 5 TO CONTINUE ROUTING
 TYPE 6 TO CONTINUE SCANNING REAL DATA
 TYPE 7 TO CALL GATE SETTINGS
 TYPE 8 TO STOP

  2

  ENTER MODEL STARTING TIME
   HR MN DAY

   15 06 219
  IOPS4*R

  PROGRAM CONTROL PREVIOUS CHAIN   5  MODEL TIME  219 17  6

  0

  TYPE NUMBER AGAIN

  9

  TYPE NUMBER AGAIN

  7

  PROGRAM CONTROL PREVIOUS CHAIN   2  MODEL TIME  219 17  6

  8

  STOP  777777

  MONITOR V40
```

Exhibit 7
Partial listing of input rainfall data (RASR70 219)

Shown is the time of reading (day, hr, min.), raingage number and mnemonics and accumulated rainfall (inches)

```
219  8 30   641 UM-RG    -0.064
219  9 30   641 UM-RG    -0.008
219 13 56   641 UM-RG    -0.010
219 14 24   641 UM-RG    -0.021
219 14 31   641 UM-RG    -0.009
219 14 41   641 UM-RG    -0.013
219 14 52   641 UM-RG    -0.008
219 15  6   641 UM-RG     0.002
219 15 24   641 UM-RG    -0.006
219 15 31   641 UM-RG     0.023
219 15 41   641 UM-RG     0.058
219 15 50   641 UM-RG     0.065
219 15 55   641 UM-RG     0.099
219 16  0   641 UM-RG     0.128
219 16 20   641 UM-RG     0.265
219 16 23   641 UM-RG     0.283
219 16 40   641 UM-RG     0.324
219 16 47   641 UM-RG     0.331
219 17 12   641 UM-RG     0.381
219 17 37   641 UM-RG     0.418
219 17 48   641 UM-RG     0.438
219 18  1   641 UM-RG     0.449
219 18  9   641 UM-RG     0.457
219 18 19   641 UM-RG     0.476
219 18 30   641 UM-RG     0.484
219 18 38   641 UM-RG     0.494
219 18 48   641 UM-RG     0.492
219 18 58   641 UM-RG     0.500
219 19  8   641 UM-RG     0.518
219 19 18   641 UM-RG     0.520
219 19 29   641 UM-RG     0.515
219 19 38   641 UM-RG     0.519
219 19 49   641 UM-RG     0.523
219 19 59   641 UM-RG     0.545
219 20  9   641 UM-RG     0.532
219 20 19   641 UM-RG     0.544
219 20 47   641 UM-RG     0.549
219 20 57   641 UM-RG     0.538
219 21  7   641 UM-RG     0.540
219 21 17   641 UM-RG     0.540
219 21 27   641 UM-RG     0.537
219 21 37   641 UM-RG     0.542
219 21 50   641 UM-RG     0.538
219 22  0   641 UM-RG     0.546
219 22 13   641 UM-RG     0.532
219 22 23   641 UM-RG     0.492
219 22 33   641 UM-RG     0.529
219 22 44   641 UM-RG     0.541
219 22 56   641 UM-RG     0.542
219 23  6   641 UM-RG     0.538
219 23 16   641 UM-RG     0.540
219 23 27   641 UM-RG     0.533
219 23 50   641 UM-RG     0.539
220  0  2   641 UM-RG     0.546
220  0 13   641 UM-RG     0.544
220  0 23   641 UM-RG     0.541
220  0 33   641 UM-RG     0.541
```

Exhibits 8-12 show part of the line printer output for the same run shown in Exhibit 6.

Exhibit 8

Partial output of rainfall loss analysis.

The rainfall file name is shown at the upper right. The nine raingages and their corresponding 5 minutes intensities for the period ending at 16:11 day 219 are given next. The remaining table shows the rainfall loss and excess on each of the 15 basins. Unless specified all values are given in inches for the 5 minute period ending at the time shown. The definition of the column mnemonics are given below.

I	– basin index
RAIN	– Average rainfall over basin
ISTLOS	– Accumulated value of initial loss on impervious surfaces.
PSTLOS	– Accumulated value of initial loss on pervious surfaces.
IINLOS	– Contribution to initial loss on impervious surfaces.
PINLOS	– Contribution to initial loss on pervious surfaces
ILOSCOE	– Impervious loss coefficient-dimensionless.
PPOTLOS	– Potential loss on pervious surfaces.
ILOSS	– Loss on impervious surfaces.
PLOSS	– Loss on pervious surfaces.
IEXS	– Excess on impervious surfaces.
PEXS	– Excess on pervious surfaces.
BASLOS	– Average basin loss.
BASEXS	– Average basin excess.
BMC	– Accumulated losses on pervious surfaces.
ACCLOSS	– Accumulated losses on impervious surfaces.

```
RAINGAGE READINGS AT 5 MINUTE INTERVALS IN (IN/HR) FOR INTERVAL ENDING AT TIME SHOWN          RAINFALL FILE - RASR70219

     GAGE NO.            1          2          3          4          5          6          7          8          9         HR MN DAY

                       MAC-       EDN-       VIL-       WTP-       VAD-       HAZ-       FIR-       UM-R       EUS-
READINGS AND TIME    0.06286    0.08572    0.16500    0.00000    0.27900    0.09900    0.21300    0.41100    0.28200        16 11 219

     I    RAIN    ISTLOS   PSTLOS  IINLOS PINLOS ILOSCOE PPOTLOS   ILOSS   PLOSS    IEXS     PEXS    BASLOS  BASEXS   BMCACCLOSS./

     1   0.0092  0.0000  0.0792  0.0000  0.0092  0.8869  0.1792  0.0082  0.0000  0.0010  0.0000  0.0085  0.0007  0.0792  0.0682
     2   0.0198  0.0000  0.1195  0.0000  0.0198  0.8353  0.1774  0.0166  0.0000  0.0033  0.0000  0.0184  0.0015  0.1198  0.1066
     3   0.0090  0.0000  0.0690  0.0000  0.0090  0.8869  0.1798  0.0080  0.0000  0.0010  0.0000  0.0083  0.0007  0.0690  0.0680
     4   0.0195  0.0000  0.1495  0.0000  0.0195  0.7866  0.1757  0.0153  0.0000  0.0042  0.0000  0.0167  0.0026  0.1495  0.1353
     5   0.0217  0.0000  0.1817  0.0000  0.0217  0.7558  0.1739  0.0164  0.0000  0.0053  0.0000  0.0181  0.0036  0.1817  0.1564
     6   0.0235  0.0000  0.2500  0.0000  0.0000  0.6440  0.1672  0.0151  0.0235  0.0084  0.0000  0.0181  0.0054  0.2935  0.2351
     7   0.0198  0.0000  0.2498  0.0000  0.0198  0.6839  0.1697  0.0136  0.0000  0.0063  0.0000  0.0155  0.0044  0.2498  0.2036
     8   0.0278  0.0000  0.2500  0.0000  0.0200  0.6839  0.1697  0.0190  0.0078  0.0088  0.0000  0.0236  0.0042  0.2578  0.2090
     9   0.0299  0.0000  0.2399  0.0000  0.0299  0.6977  0.1709  0.0209  0.0000  0.0091  0.0000  0.0236  0.0063  0.2399  0.2009
    10   0.0092  0.0000  0.1192  0.0000  0.0092  0.8187  0.1769  0.0075  0.0000  0.0017  0.0000  0.0082  0.0010  0.1192  0.1075
    11   0.0149  0.0000  0.1749  0.0000  0.0149  0.7558  0.1739  0.0113  0.0000  0.0036  0.0000  0.0124  0.0026  0.1749  0.1513
    12   0.0052  0.0000  0.0552  0.0000  0.0052  0.9048  0.1804  0.0047  0.0000  0.0005  0.0000  0.0049  0.0003  0.0552  0.0547
    13   0.0222  0.0000  0.2500  0.0000  0.0000  0.6571  0.1685  0.0146  0.0222  0.0076  0.0000  0.0168  0.0054  0.2722  0.2246
    14   0.0186  0.0000  0.2186  0.0000  0.0186  0.7118  0.1715  0.0133  0.0000  0.0054  0.0000  0.0149  0.0037  0.2186  0.1833
    15   0.0000  0.0000  0.0700  0.0000  0.0000  0.8694  0.1792  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0700  0.0700

                       MAC-       EDN-       VIL-       WTP-       VAD-       HAZ-       FIR-       UM-R       EUS-
READINGS AND TIME    0.06286    0.08572    0.16500    0.00000    0.27900    0.09900    0.21300    0.41100    0.28201        16 16 219

     I    RAIN    ISTLOS   PSTLOS  IINLOS PINLOS ILOSCOE PPOTLOS   ILOSS   PLOSS    IEXS     PEXS    BASLOS  BASEXS   BMCACCLOSS./

     1   0.0092  0.0000  0.0884  0.0000  0.0092  0.8726  0.1787  0.0080  0.0000  0.0012  0.0000  0.0084  0.0008  0.0884  0.0762
     2   0.0198  0.0000  0.1397  0.0000  0.0198  0.8080  0.1763  0.0160  0.0000  0.0038  0.0000  0.0181  0.0017  0.1397  0.1226
     3   0.0090  0.0000  0.0780  0.0000  0.0090  0.8729  0.1793  0.0078  0.0000  0.0011  0.0000  0.0082  0.0008  0.0780  0.0758
     4   0.0195  0.0000  0.1689  0.0000  0.0195  0.7629  0.1745  0.0149  0.0000  0.0046  0.0000  0.0164  0.0031  0.1689  0.1502
     5   0.0217  0.0000  0.2034  0.0000  0.0217  0.7314  0.1726  0.0159  0.0000  0.0058  0.0000  0.0178  0.0039  0.2034  0.1723
     6   0.0235  0.0000  0.2500  0.0000  0.0000  0.6248  0.1658  0.0147  0.0235  0.0088  0.0000  0.0179  0.0056  0.3170  0.2498
     7   0.0198  0.0000  0.2500  0.0000  0.0002  0.6656  0.1685  0.0132  0.0197  0.0066  0.0000  0.0152  0.0046  0.2697  0.2168
     8   0.0278  0.0000  0.2500  0.0000  0.0000  0.6584  0.1680  0.0183  0.0278  0.0095  0.0000  0.0232  0.0046  0.2856  0.2273
     9   0.0299  0.0000  0.2500  0.0000  0.0101  0.6691  0.1691  0.0200  0.0199  0.0099  0.0000  0.0230  0.0069  0.2699  0.2209
    10   0.0092  0.0000  0.1284  0.0000  0.0092  0.8065  0.1763  0.0074  0.0000  0.0018  0.0000  0.0081  0.0011  0.1284  0.1150
    11   0.0149  0.0000  0.1899  0.0000  0.0149  0.7389  0.1730  0.0110  0.0000  0.0039  0.0000  0.0122  0.0027  0.1899  0.1623
    12   0.0052  0.0000  0.0605  0.0000  0.0052  0.8963  0.1801  0.0047  0.0000  0.0005  0.0000  0.0049  0.0003  0.0605  0.0594
    13   0.0222  0.0000  0.2500  0.0000  0.0000  0.6382  0.1671  0.0142  0.0222  0.0080  0.0000  0.0165  0.0057  0.2944  0.2387
    14   0.0186  0.0000  0.2372  0.0000  0.0186  0.6932  0.1704  0.0129  0.0000  0.0057  0.0000  0.0147  0.0039  0.2372  0.1962
    15   0.0000  0.0000  0.0700  0.0000  0.0000  0.8694  0.1792  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0700  0.0700

                       MAC-       EDN-       VIL-       WTP-       VAD-       HAZ-       FIR-       UM-R       EJS-
READINGS AND TIME    0.06285    0.08571    0.14000    0.00000    0.32321    0.09920    0.15440    0.40081    0.28200        16 21 219

     I    RAIN    ISTLOS   PSTLOS  IINLOS PINLOS ILOSCOE PPOTLOS   ILOSS   PLOSS    IEXS     PEXS    BASLOS  BASEXS   BMCACCLOSS./

     1   0.0087  0.0000  0.0971  0.0000  0.0087  0.8587  0.1781  0.0075  0.0000  0.0012  0.0000  0.0079  0.0009  0.0971  0.0837
     2   0.0176  0.0000  0.1573  0.0000  0.0176  0.7825  0.1751  0.0138  0.0000  0.0038  0.0000  0.0159  0.0017  0.1573  0.1364
     3   0.0075  0.0000  0.0855  0.0000  0.0075  0.8593  0.1788  0.0065  0.0000  0.0011  0.0000  0.0068  0.0007  0.0855  0.0823
     4   0.0161  0.0000  0.1850  0.0000  0.0161  0.7406  0.1733  0.0119  0.0000  0.0042  0.0000  0.0133  0.0028  0.1650  0.1621
     5   0.0192  0.0000  0.2226  0.0000  0.0192  0.7086  0.1713  0.0136  0.0000  0.0056  0.0000  0.0154  0.0037  0.2226  0.1859
     6   0.0235  0.0000  0.2500  0.0000  0.0000  0.6068  0.1644  0.0143  0.0235  0.0092  0.0000  0.0176  0.0059  0.3405  0.2641
     7   0.0198  0.0000  0.2500  0.0000  0.0000  0.6482  0.1673  0.0129  0.0198  0.0070  0.0000  0.0150  0.0049  0.2895  0.2296
     8   0.0275  0.0000  0.2500  0.0000  0.0000  0.6347  0.1663  0.0174  0.0275  0.0100  0.0000  0.0226  0.0048  0.3131  0.2447
     9   0.0294  0.0000  0.25uu  0.0000  0.0000  0.6428  0.1672  0.0189  0.0294  0.0105  0.0000  0.0221  0.0074  0.2993  0.2399
    10   0.0090  0.0000  0.1374  0.0000  0.0090  0.7946  0.1758  0.0072  0.0000  0.0019  0.0000  0.0079  0.0011  0.1374  0.1221
```

Exhibit 9

Partial listing of calculated inlet hydrographs.

Points on hydrograph are given at 5 minute intervals from −34 to +50 periods relative to point zero which corresponds to 16:06 day 219. Read horizontally left to right. Discharge in cfs.

```
UNDIVERTED HYDROGRAPHS
POINT  0 REPRESENTS PRESENT MODEL TIME    16   6 219      POINTS ARE AT 5 MINUTE INTERVALS

INTPH HYDROGRAPH NO.    1
 -34    8.0-33   8.0-32   8.0-31   8.0-30   8.0-29   8.0-28   8.0-27   8.0-26   8.0-25   8.2-24   8.2-23   8.2
 -22    8.2-21   8.2-20   8.2-19   8.2-18   8.2-17   8.2-16   8.2-15   8.2-14   8.2-13   8.4-12   8.4-11   8.4
 -10    8.4 -9   8.4 -8   8.4 -7   8.4 -6   8.4 -5   8.5 -4   8.5 -3   8.6 -2   8.8 -1   9.2  0   9.8  1  10.7
   2   11.3  3  11.5  4  11.4  5  11.2  6  11.1  7  10.9  8  10.7  9  10.6 10  10.4 11  10.1 12  10.0 13   9.8
  14    9.6 15   9.5 16   9.3 17   9.2 18   9.0 19   8.9 20   8.7 21   8.6 22   8.4 23   8.1 24   8.0 25   8.0
  26    8.0 27   8.0 28   8.0 29   8.0 30   8.0 31   8.0 32   8.0 33   8.0 34   8.0 35   7.7 36   7.7 37   7.7
  38    7.7 39   7.7 40   7.7 41   7.7 42   7.7 43   7.7 44   7.7 45   7.7 46   7.7 47   7.4 48   7.4 49   7.4
  50    7.4

INTTR HYDROGRAPH NO.    2
 -34   19.2-33  19.2-32  19.2-31  19.2-30  19.2-29  19.2-28  19.2-27  19.2-26  19.2-25  19.7-24  19.7-23  19.7
 -22   19.7-21  19.7-20  19.7-19  19.7-18  19.7-17  19.7-16  19.7-15  19.7-14  19.7-13  20.0-12  20.0-11  20.0
 -10   20.0 -9  20.0 -8  20.0 -7  20.0 -6  20.0 -5  20.0 -4  20.1 -3  20.2 -2  20.3 -1  20.7  0  21.1  1  21.7
   2   22.2  3  22.8  4  23.3  5  23.7  6  23.8  7  23.7  8  23.7  9  23.6 10  23.5 11  23.1 12  23.0 13  23.0
  14   22.9 15  22.8 16  22.7 17  22.6 18  22.6 19  22.5 20  22.4 21  22.3 22  22.2 23  21.5 24  21.4 25  21.4
  26   21.3 27  21.2 28  21.1 29  21.1 30  21.0 31  20.9 32  20.8 33  20.7 34  20.7 35  19.8 36  19.7 37  19.6
  38   19.5 39  19.5 40  19.4 41  19.3 42  19.2 43  19.2 44  19.1 45  19.0 46  18.9 47  18.2 48  18.1 49  18.0
  50   18.0

DAVNI HYDROGRAPH NO.    3
 -34    4.6-33   4.6-32   4.6-31   4.6-30   4.6-29   4.6-28   4.6-27   4.6-26   4.6-25   4.7-24   4.7-23   4.7
 -22    4.7-21   4.7-20   4.7-19   4.7-18   4.7-17   4.7-16   4.7-15   4.7-14   4.7-13   4.7-12   4.7-11   4.7
 -10    4.7 -9   4.8 -8   4.8 -7   4.8 -6   4.8 -5   4.8 -4   4.9 -3   5.2 -2   5.7 -1   6.4  0   7.1  1   8.0
   2    8.2  3   7.9  4   6.7  5   5.8  6   5.2  7   4.8  8   4.8  9   4.8 10   4.8 11   4.7 12   4.7 13   4.7
  14    4.7 15   4.7 16   4.7 17   4.7 18   4.7 19   4.7 20   4.7 21   4.7 22   4.7 23   4.6 24   4.6 25   4.6
  26    4.6 27   4.6 28   4.6 29   4.6 30   4.6 31   4.6 32   4.6 33   4.6 34   4.6 35   4.4 36   4.4 37   4.4
  38    4.4 39   4.4 40   4.4 41   4.4 42   4.4 43   4.4 44   4.4 45   4.4 46   4.4 47   4.2 48   4.2 49   4.2
  50    4.2

KELOI HYDROGRAPH NO.    4
 -34    7.3-33   7.3-32   7.3-31   7.3-30   7.3-29   7.3-28   7.3-27   7.3-26   7.3-25   7.5-24   7.5-23   7.5
 -22    7.5-21   7.5-20   7.5-19   7.5-18   7.5-17   7.5-16   7.5-15   7.5-14   7.5-13   7.6-12   7.6-11   7.6
 -10    7.6 -9   7.6 -8   7.7 -7   7.8 -6   8.0 -5   8.3 -4   8.9 -3  10.9 -2  15.3 -1  25.1  0  38.7  1  54.8
   2   62.9  3  62.9  4  54.4  5  45.8  6  37.4  7  29.1  8  21.3  9  14.6 10  10.0 11   7.6 12   7.6 13   7.6
  14    7.6 15   7.6 16   7.6 17   7.6 18   7.6 19   7.6 20   7.6 21   7.6 22   7.6 23   7.3 24   7.3 25   7.3
  26    7.3 27   7.3 28   7.3 29   7.3 30   7.3 31   7.3 32   7.3 33   7.3 34   7.3 35   7.0 36   7.0 37   7.0
  38    7.0 39   7.0 40   7.0 41   7.0 42   7.0 43   7.0 44   7.0 45   7.0 46   7.0 47   6.8 48   6.8 49   6.8
  50    6.8
```

Exhibit 10

Partial listing of hydrographs diverted into the interceptor at major inlets before lumping parameters are applied.

```
DIVERTED HYDROGRAPHS
POINT 0 REPRESENTS PRESENT MODEL TIME    16   6 219      DISCHARGE AT 5 MINUTE INTERVALS

INTPH    HYDROGRAPH NO.    1
 -34    8.0-33   8.0-32   8.0-31   8.0-30   8.0-29   8.0-28   8.0-27   8.0-26   8.0-25   8.2-24   8.2-23   8.2
 -22    8.2-21   8.2-20   8.2-19   8.2-18   8.2-17   8.2-16   8.2-15   8.2-14   8.2-13   8.4-12   8.4-11   8.4
 -10    8.4 -9   8.4 -8   8.4 -7   8.4 -6   8.4 -5   8.5 -4   8.5 -3   8.6 -2   8.8 -1   9.2  0   9.8  1  10.7
   2   11.3  3  11.5  4  11.4  5  11.2  6  11.1  7  10.9  8  10.7  9  10.6 10  10.4 11  10.1 12  10.0 13   9.8
  14    9.6 15   9.5 16   9.3 17   9.2 18   9.0 19   8.9 20   8.7 21   8.6 22   8.4 23   8.1 24   8.0 25   8.0
  26    8.0 27   8.0 28   8.0 29   8.0 30   8.0 31   8.0 32   8.0 33   8.0 34   8.0 35   7.7 36   7.7 37   7.7
  38    7.7 39   7.7 40   7.7 41   7.7 42   7.7 43   7.7 44   7.7 45   7.7 46   7.7 47   7.4 48   7.4 49   7.4
  50    7.4

INTTR    HYDROGRAPH NO.    2
 -34   19.2-33  19.2-32  19.2-31  19.2-30  19.2-29  19.2-28  19.2-27  19.2-26  19.2-25  19.7-24  19.7-23  19.7
 -22   19.7-21  19.7-20  19.7-19  19.7-18  19.7-17  19.7-16  19.7-15  19.7-14  19.7-13  20.0-12  20.0-11  20.0
 -10   20.0 -9  20.0 -8  20.0 -7  20.0 -6  20.0 -5  20.0 -4  20.1 -3  20.2 -2  20.3 -1  20.7  0  21.1  1  21.7
   2   22.2  3  22.8  4  23.3  5  23.7  6  23.8  7  23.7  8  23.7  9  23.6 10  23.5 11  23.1 12  23.0 13  23.0
  14   22.9 15  22.8 16  22.7 17  22.6 18  22.6 19  22.5 20  22.4 21  22.3 22  22.2 23  21.5 24  21.4 25  21.4
  26   21.3 27  21.2 28  21.1 29  21.1 30  21.0 31  20.9 32  20.8 33  20.7 34  20.7 35  19.8 36  19.7 37  19.6
  38   19.5 39  19.5 40  19.4 41  19.3 42  19.2 43  19.2 44  19.1 45  19.0 46  18.9 47  18.2 48  18.1 49  18.0
  50   18.0

DAVNI    HYDROGRAPH NO.    3
 -34    4.6-33   4.6-32   4.6-31   4.6-30   4.6-29   4.6-28   4.6-27   4.6-26   4.6-25   4.7-24   4.7-23   4.7
 -22    4.7-21   4.7-20   4.7-19   4.7-18   4.7-17   4.7-16   4.7-15   4.7-14   4.7-13   4.7-12   4.7-11   4.7
 -10    4.7 -9   4.8 -8   4.8 -7   4.8 -6   4.8 -5   4.8 -4   4.9 -3   5.2 -2   5.7 -1   6.4  0   7.1  1   8.0
   2    8.2  3   7.9  4   6.7  5   5.8  6   5.2  7   4.8  8   4.8  9   4.8 10   4.8 11   4.7 12   4.7 13   4.7
  14    4.7 15   4.7 16   4.7 17   4.7 18   4.7 19   4.7 20   4.7 21   4.7 22   4.7 23   4.6 24   4.6 25   4.6
  26    4.6 27   4.6 28   4.6 29   4.6 30   4.6 31   4.6 32   4.6 33   4.6 34   4.6 35   4.4 36   4.4 37   4.4
  38    4.4 39   4.4 40   4.4 41   4.4 42   4.4 43   4.4 44   4.4 45   4.4 46   4.4 47   4.2 48   4.2 49   4.2
  50    4.2

KELOI    HYDROGRAPH NO.    4
 -34    7.3-33   7.3-32   7.3-31   7.3-30   7.3-29   7.3-28   7.3-27   7.3-26   7.3-25   7.5-24   7.5-23   7.5
 -22    7.5-21   7.5-20   7.5-19   7.5-18   7.5-17   7.5-16   7.5-15   7.5-14   7.5-13   7.6-12   7.6-11   7.6
 -10    7.6 -9   7.6 -8   7.7 -7   7.8 -6   8.0 -5   8.3 -4   8.9 -3  10.9 -2  15.3 -1  25.1  0  36.3  1  37.7
   2   43.2  3  43.3  4  37.4  5  37.2  6  35.0  7  29.1  8  21.3  9  14.6 10  10.0 11   7.6 12   7.6 13   7.6
  14    7.6 15   7.6 16   7.6 17   7.6 18   7.6 19   7.6 20   7.6 21   7.6 22   7.6 23   7.3 24   7.3 25   7.3
  26    7.3 27   7.3 28   7.3 29   7.3 30   7.3 31   7.3 32   7.3 33   7.3 34   7.3 35   7.0 36   7.0 37   7.0
  38    7.0 39   7.0 40   7.0 41   7.0 42   7.0 43   7.0 44   7.0 45   7.0 46   7.0 47   6.8 48   6.8 49   6.8
  50    6.8
```

Exhibit 11

Partial listing of flow diverted into interceptor after lumping factor applied.

```
DIVERTED HYDROGRAPHS
POINT 0 REPRESENTS PRESENT MODEL TIME    16   6 219      DISCHARGE AT 5 MINUTE INTERVALS

INTPH   HYDROGRAPH NO.      1
-34     31.8-33     31.8-32     31.8-31     31.8-30     31.8-29     31.8-28     31.8-27     31.8-26     31.8-25     32.6-24     32.6-23     32.6
-22     32.6-21     32.6-20     32.6-19     32.6-18     32.6-17     32.6-16     32.6-15     32.6-14     32.6-13     33.2-12     33.2-11     33.2
-10     33.2 -9     33.2 -8     33.2 -7     33.3 -6     33.3 -5     33.5 -4     33.8 -3     34.1 -2     34.9 -1     36.4  0     39.0  1     42.5
  2     44.9  3     45.7  4     45.0  5     44.4  6     43.8  7     43.1  8     42.5  9     41.9 10     41.3 11     40.1 12     39.5 13     38.8
 14     38.2 15     37.6 16     36.9 17     36.3 18     35.7 19     35.1 20     34.5 21     34.0 22     33.5 23     32.0 24     31.8 25     31.8
 26     31.8 27     31.8 28     31.8 29     31.8 30     31.8 31     31.8 32     31.8 33     31.8 34     31.8 35     30.5 36     30.5 37     30.5
 38     30.5 39     30.5 40     30.5 41     30.5 42     30.5 43     30.5 44     30.5 45     30.5 46     30.5 47     29.5 48     29.5 49     29.5



 50     29.5

INTTR   HYDROGRAPH NO.      2
-34     20.4-33     20.4-32     20.4-31     20.4-30     20.4-29     20.4-28     20.4-27     20.4-26     20.4-25     20.9-24     20.9-23     20.9
-22     20.9-21     20.9-20     20.9-19     20.9-18     20.9-17     20.9-16     20.9-15     20.9-14     20.9-13     21.2-12     21.2-11     21.2
-10     21.2 -9     21.2 -8     21.2 -7     21.2 -6     21.2 -5     21.2 -4     21.3 -3     21.4 -2     21.5 -1     21.9  0     22.3  1     23.0
  2     23.6  3     24.2  4     24.7  5     25.1  6     25.3  7     25.2  8     25.1  9     25.0 10     24.9 11     24.5 12     24.4 13     24.3
 14     24.2 15     24.2 16     24.1 17     24.0 18     23.9 19     23.8 20     23.7 21     23.7 22     23.6 23     22.8 24     22.7 25     22.7
 26     22.6 27     22.5 28     22.4 29     22.3 30     22.2 31     22.2 32     22.1 33     22.0 34     21.9 35     21.0 36     20.9 37     20.8
 38     20.7 39     20.6 40     20.6 41     20.5 42     20.4 43     20.3 44     20.2 45     20.1 46     20.1 47     19.3 48     19.2 49     19.1
 50     19.0

DAVNI   HYDROGRAPH NO.      3
-34      7.2-33      7.2-32      7.2-31      7.2-30      7.2-29      7.2-28      7.2-27      7.2-26      7.2-25      7.4-24      7.4-23      7.4
-22      7.4-21      7.4-20      7.4-19      7.4-18      7.4-17      7.4-16      7.4-15      7.4-14      7.4-13      7.5-12      7.5-11      7.5
-10      7.5 -9      7.5 -8      7.5 -7      7.5 -6      7.5 -5      7.6 -4      7.8 -3      8.2 -2      8.9 -1     10.1  0     11.3  1     12.7
  2     12.9  3     12.4  4     10.7  5      9.2  6      8.2  7      7.6  8      7.6  9      7.6 10      7.6 11      7.4 12      7.4 13      7.4
 14      7.4 15      7.4 16      7.4 17      7.4 18      7.4 19      7.4 20      7.4 21      7.4 22      7.4 23      7.2 24      7.2 25      7.2
 26      7.2 27      7.2 28      7.2 29      7.2 30      7.2 31      7.2 32      7.2 33      7.2 34      7.2 35      6.9 36      6.9 37      6.9
 38      6.9 39      6.9 40      6.9 41      6.9 42      6.9 43      6.9 44      6.9 45      6.9 46      6.9 47      6.7 48      6.7 49      6.7
 50      6.7

KELOI   HYDROGRAPH NO.      4
-34     11.1-33     11.1-32     11.1-31     11.1-30     11.1-29     11.1-28     11.1-27     11.1-26     11.1-25     11.4-24     11.4-23     11.4
-22     11.4-21     11.4-20     11.4-19     11.4-18     11.4-17     11.4-16     11.4-15     11.4-14     11.4-13     11.6-12     11.6-11     11.6
-10     11.6 -9     11.6 -8     11.7 -7     11.9 -6     12.1 -5     12.6 -4     13.6 -3     16.6 -2     23.3 -1     38.1  0     55.2  1     57.3
  2     65.7  3     65.7  4     56.8  5     56.6  6     53.3  7     44.2  8     32.4  9     22.1 10     15.2 11     11.5 12     11.5 13     11.5
 14     11.5 15     11.5 16     11.5 17     11.5 18     11.5 19     11.5 20     11.5 21     11.5 22     11.5 23     11.1 24     11.1 25     11.1
 26     11.1 27     11.1 28     11.1 29     11.1 30     11.1 31     11.1 32     11.1 33     11.1 34     11.1 35     10.7 36     10.7 37     10.7
 38     10.7 39     10.7 40     10.7 41     10.7 42     10.7 43     10.7 44     10.7 45     10.7 46     10.7 47     10.3 48     10.3 49     10.3
 50     10.3
```

Exhibit 12

Summary of volumes before and after diversion.

```
INLET INDEX  LUMPED INLET VOL   LUMPED DIV VOL  LUMPED RIVER VOL     INLET VOL     DIVERTED VOL      RIVER VOL
     1               859913.          859913.              0.        217151.         217151.             0.
     2               551537.          551537.              0.        520326.         520326.             0.
     3               192652.          192652.              0.        121933.         121933.             0.
     4               456368.          416791.          39577.        300244.         274206.         26038.
     5               357869.          357870.             -0.        357868.         357868.            -0.
     6               371116.          364082.           7034.        231950.         227554.          4396.
     7               494705.          354566.         140137.        173582.         124411.         49172.
     8               768316.          720288.          48027.        768314.         720286.         48027.
     9               739502.          739502.             -0.        406322.         406322.            -0.
    10               903750.          903750.              0.        331045.         331045.             0.
    11               697681.          695514.           2167.        581407.         579602.          1806.
    12              1110914.         1044109.          66809.        983127.         924002.         59124.
    13               816953.          816953.              0.        614256.         614256.             0.
    14              1249695.         1249695.              0.        844399.         844399.             0.
    15               645588.          645588.              0.        180333.         180333.             0.
 TOTAL VOLUME CF    10216634.         9912878.         303751.       6632271.        6443706.        188563.
 TOTAL VOLUME MG       76.42            74.15            2.27          49.61           48.20           1.41
```

Exhibit 13

6. Loader Memory maps of CREATE and MODEL (UROM-9)

```
MONITOR V4B

$A DKA -6,-4,-1,3,10

$CHAIN


CHAIN V2A
>BUILD CREATE
>CHAIN 1
>CREAT2,INPUTD,INPUTH,ROUTJN
>END
 CREAT2 55602
 INPUTD 54051
 INPUTH 52373
 ROUTJN 51460
 DKA.   45462
 LPA.   45074
 FILE   44541
 FLOAT  44530
 .DA    44461
 BCDIO  41432
 BINIO  41156
 .SS    41076
 STOP   41063
 SPMSG  40770
 FIOPS  40230
 OTSER  40134
 INTEGE 37661
 REAL   36625
 .CB    40114

 CHAIN# 1
 LOWEST 31537
 COMSZE 00000

>CLOSE



 MONITOR V4B

 $B PR

 MONITOR V4B

 $$JOB BUILD MODEL.

 $A DKA -6,-4,-1,3,7,10/LPA 4

 $CHAIN


 CHAIN V2A
 >BUILD MODEL
 >CHAIN 1
 >CHAIN1,SENSE,SET,TMADD
 >END
  CHAIN1 54545
  SENSE  54514
  SET    54167
  TMADD  53723
  DKA.   47725
  FILE   47372
  .DA    47323
  BCDIO  44274
  BINIO  44020
  .SS    43740
  STOP   43725
  PAUSE  43711
  SPMSG  43616
  FIOPS  43056
  OTSER  42760
  INTEGE 42643
  REAL   41607
  .CB    41567

  CHAIN# 1
  LOWEST 41567
  COMSZE 07305



 >CHAIN 2
 >CHAIN2,CONTL,GATEDT,EVNTL,TMADD,SENSE,RAINF
 >END
  CHAIN2 56410
  CONTL  55421
  GATEDT 53411
  EVNTL  52246
  TMADD  52002
  SENSE  51751
  RAINF  47111
  DKA.   43113
  LPA.   42525
  FILE   42172
  IABS   42156
  .DA    42107
```

```
BCDIO  34751
BINIO  41633
.SS    41553
GOTO   41525
STOP   41512
SPMSG  41417
FIOPS  40657
OTSER  40563
INTEGE 40444
REAL   33715
.CB    40424

CHAIN# 2
LOWEST 33265
COMSZE 07305



>CHAIN 3
>CHAIN3,HYDR,SLOS,SENSE,TMADD
>END
 CHAIN3 55607
 HYDR   53435
 SLOS   52152
 SENSE  52121
 TMADD  51655
 DKA.   45657
 LPA.   45271
 FILE   44736
 FLOAT  44725
 .BE    44672
 EXP    44657
 .EE    44566
 .EF    44450
 .EC    44404
 .DA    44335
 BCDIO  41306
 BINIO  41032
 .SS    40752
 STOP   40737
 SPMSG  40644
 FIOPS  40104
 OTSER  37704
 INTEGE 37565
 REAL   36531
 .CB    40064

 CHAIN# 3
 LOWEST 34777
 COMSZE 07305



 >CHAIN 4
 >CHAIN4,DIV,TY1,TY2,TY4,TY5,AREA,BICC,TOP,CRES,SENSE,TRAPOZ,
 >TMADD,FABGTS
 >END
  CHAIN4 54732
  DIV    53232
  TY1    52601
  TY2    52202
  TY4    51543
  TY5    50436
  AREA   50065
  BICC   47703
  TOP    47566
  CRES   47464
  SENSE  47433
  TRAPOZ 47226
  TMADD  46762
  FABGTS 46521
  DKA.   42523
  LPA.   42135
  FILE   41602
  ABS    41564
  .BC    41510
  .BE    41455
  SQRT   41367
  SIN    41354
  ATAN   41341
  .EB    41237
  .ED    41150
  .EE    41057
  .EF    40741
  .EC    40675
  .DA    40626
  BCDIO  34751
  BINIO  40352
  .SS    40272
  GOTO   40244
  STOP   40231
  SPMSG  40136
  FIOPS  34211
  OTSER  40042
  INTEGE 34072
  REAL   33036
  .CB    40022

  CHAIN# 4
  LOWEST 32046
  COMSZE 07305
```

```
>CHAIN 5
>CHAINS,ROUTB,COMB,DIVIN,VALY,AREA,SENSE,TY1,TY7,FABGTS,THADD,
>CRES,TOP,BICC,TRAPOZ
>END
 CHAINS 55715
 ROUTB  54576
 COMB   54414
 DIVIN  53400
 VALY   53035
 AREA   52464
 SENSE  52433
 TY1    52000
 TY7    51636
 FABGTS 51375
 THADD  51131
 CRES   51027
 TOP    50712
 BICC   50530
 TRAPOZ 50323
 DHA.   44325
 LPA.   43737
 FILE   43404
 ABS    43366
 IABS   43350
 MOD    43326
 .BC    43250
 .BE    43217
 SQRT   43131
 SIN    43116
 ATAN   43103
 .EB    43001
 .ED    42712
 .EE    42621
 .EF    42503
 .EC    42437
 .DA    42370
 BCDIO  34751
 BINIO  42114
 .SS    42034
 GOTO   42006
 STOP   41773
 SPMSG  41700
 FIOPS  41140
 OTSER  41044
 INTEGE 40725
 REAL   33715
 .CB    40705

 CHAIN# 5
 LOWEST 32264
 COMSZE 07305




>CHAIN 9
>SCHDL2,SCALER,RIVMON,REGCTL,INCPTR,RAINRP,ALARMR,SETGAT,
>INTRPT,SCHFRQ,TIMR,POINT,CONSV,TIME
>RGATE,SENSE
>END
 SCHDL2 56432
 SCALER 55575
 RIVMON 54407
 REGCTL 53304
 INCPTR 52333
 RAINRP 51225
 ALARMR 50322
 SETGAT 47504
 INTRPT 47411
 SCHFRQ 47063
 TIMR   46727
 POINT  46455
 CONSV  46401
 TIME   46310
 RGATE  46102
 SENSE  46051
 DHA.   42053
 LPA.   41465
 FILE   41132
 IABS   41116
 .BB    41040
 .DA    40771
 BCDIO  34751
 .SS    40711
 STOP   40676
 SPMSG  40603
 FIOPS  40043
 OTSER  34655
 INTEGE 34536
 REAL   33502
 .CB    40023

 CHAIN# 11
 LOWEST 33502
 COMSZE 07303

>CLOSE
```

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APPENDIX B

Description of Labels Used in CREATE and UROM-9

If the same label is used in different routines to represent different variables, the name of each routine is shown with the appropriate description. An asterisk (*) indicates that the label may indicate a type other than that implied by the label name.

Label	**Routine(s)**	**Description**
A	– – –	Not used
	(TYPE 4)	See AO
	(HYDR)	See AREA
ACCUM	– – –	Not used, accumulated time since loss rate recovery parameter has been applied.
AG	– – –	Temporary value
AJJ	– – –	Index in PAL routing
AJL	– – –	Index in PAL routing
ALOSC	– – –	Loss rate constants
ALPH	– – –	See NAMES
ALPHA	– – –	See NAMES
AN	– – –	Manning's "n"
ANS	– – –	See NSTRL
AO	– – –	Area of orifice opening (sq ft)
AR	(CHAIN 3)	See AREA
AREA	– – –	Combined sewer area actually contributing to given inlet (sq ft)
AVG	– – –	Average initial rainfall reading
AVG1	– – –	Average rainfall reading
A5	– – –	Area of orifice opening (sq ft)
A6	– – –	Area of orifice opening (sq ft)
BA	– – –	Temporary value
BB	– – –	Temporary value
BC	– – –	Temporary value
BD	– – –	Temporary value
BFFAC	– – –	Base flow factors–hourly factors to determine hourly base flow from mean daily
BMC	– – –	Basin moisture content (total loss on pervious surfaces)
BMSTL	– – –	File name of antecedent condition parameters (BMCXSTLOS)
CHECK	(RAINF)	*Flag
COUNT	– – –	Number of valid rainfall readings
CZ	– – –	Thiessen polygon factors
C1	(TYPE 1, TYPE 4)	C_D of Fabridams
	(TYPE 2)	C_D side channel weir
	(TYPE 5)	C_D weir A
	(TYPE 7)	C_D orifice
C10	– – –	Length of lower side weir (Type 5)
C11	– – –	C_D orifice (Type 5)
C12	– – –	Elev. lower weir (Type 5)
C13	– – –	Drop from orifice to interceptor (Type 5)
C14	– – –	Length of upper side weir (Type 5)
C15	– – –	Width of orifice (Type 5)
C2	(TYPE 1)	1/2 (32.2) (C1)
	(TYPE 2)	Length side channel weir
	(TYPE 4)	Fab. expon.
	(TYPE 5)	Length of Weir A
	(TYPE 7)	Width orif.
C3	(TYPE 1)	Fab. expon.
	(TYPE 2)	C_D gates
	(TYPE 4)	Discharge ratio
	(TYPE 5)	C_D orifice 0
C4	(TYPE 1)	Width orif.
	(TYPE 2)	Elev. weir
	(TYPE 5)	C_D Fab.
C5	– – –	Elev. orifice invert (Type 1)
C6	– – –	Expon. Fab (Type 5)
C7	– – –	Area orifice D (Type 5)
C8	– – –	Elev. upper weir (Type 5)
C9	– – –	C_D side weir (Type 5)
D	(AREA, CRES)	Nominal opening of orifice
	(GATEDT)	Hollerith "D" Delete
	(TOP)	Nominal fabridam diameter
DDT	(CONTL)	See DTT
DELT	– – –	Difference in time (hrs)
DF	– – –	Fabridam diameters (ft)
DFA	– – –	Fabridam diameter (ft)
DFF	– – –	Temporary value fabridam diameter (ft)
DIFF	– – –	Difference between current and last reading; average rainfall increase in time period
DIVC	– – –	Diversion constants (C1 through C5)
DIVCC	– – –	Diversion constants (C6 through C15)
DIVE	– – –	Common block name
DR	(EVNTL)	Difference of values
DT	– – –	Time interval of points on hydrograph (sec)
DTT	– – –	Time interval of equally spaced rain data (sec)
E	(GATEDT)	Hollerith "E" Exit

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F	---	Residual in bisection method
FACT	---	Lumping factors to account for areas that are assumed to enter interceptor at one of 15 major inlet points
GAGE	(RAINF)	Gage name
GATES	---	File name for gate and Fabridam setting file (GATESETTG)
H	(TYPE 1)	Fabridam height (ft)
	---	Gate opening (ft)
HA	---	Gate opening (ft)
HF	---	Fabridam height (ft)
HFA	---	Fabridam height (ft)
HFF	---	Fabridam height (ft)
HFFF	---	Fabridam height (ft)
HFL	---	Fabridam height (ft)
HFMAX	---	Max Fabridam height (ft)
HFMAXL	---	Max Fabridam height (ft)
HG	---	Gate opening (ft)
HGG	---	Gate opening (ft)
HGGG	---	Gate opening (ft)
HGL	---	Gate opening (ft)
HGMAX	---	Max gate opening (ft)
HGMAXL	---	Max gate opening (ft)
HS	---	Temporary value
H1	---	Temporary value
H5	---	Gate opening (ft)
H6	---	Gate opening (ft)
I	---	Index
IA	(DIVIN)	Index of diversion type
	(EVNTL)	Temp index
IADDA	---	Rain gage address
IADDR	---	Valid rain gage addresses in order used by model
IB	---	Index of meter
IC	---	No longer used
ICN	---	Number of additional lag periods if NSTRL is even
ICONTA	---	Flag indicating (0—don't print instructions to operator, 1—print)
ICONTB	---	Index of current operation in operation table (JR)
ICONTC	---	Total number of steps in operation table (JR)
ICONTD	---	Index giving last chain executed
ID	---	Time-days
IDA	---	Time-days
IDAY	---	Real time day
IDAYH	---	Diversion model time (days)
IDD	---	Time-days to begin forming even intervals
IDT	---	Time interval (sec)
IDTM	---	Time interval minutes
IDTT	(RAINF)	See IDT
IE	---	Index of operation to be done (1—routing, 2—combining, 3—diversion, 4—begin on new line)
IGT	---	Gate number
IH	---	Time-hours
	(CHAIN 5)	Index of hydrograph to be operated on
IHA	---	Time-hours
	(CHAIN 5)	Index of hydrograph to be combined
IHH	---	Index of where to store results of operation
	(ENVTL)	Time-hours to begin forming even intervals
IHR	---	Real time-hour
IHRH	---	Diversion model time (hrs)
IIB	---	Sense switch flags (0 through 17)
IJ	---	Flag for excessive flow
IK	(ROUTB)	Index
IM	---	Time minutes
IMA	---	Time minutes
IMIN	---	Real time minute
IMINH	---	Diversion model time (minutes)
IMM	---	Time-minutes to begin forming even intervals
IN	---	Index
INLAG	---	Index of hydrograph points to be logged
IO	---	INDEX
IR	(HYDR)	See NNN (RAINF)
IRI	---	Index
IS	---	Time seconds
IS	(HYDR)	Index
ISEC	---	Real time seconds
ISS	---	Time-sec to begin forming even intervals
ISTAT	---	File status flag
IT	---	Index
ITB	---	Number of time intervals for base length of unit hydrographs
ITEST	(CHAIN 1)	File status flag
ITIME	(RAINF)	Temp. storage oftimes of rainfall readings
ITIMES	---	Used by RTIME (to keep common size equal)
ITM	(CREAT 2)	Largest unit hydrograph base time (DT time intervals), no longer used

ITP	---	Number of time intervals for time to peak of unit hydrographs
ITQI	(CREAT 2)	Not used
ITT	---	Index
IX	---	Index
IXD	---	Time days
IXH	---	Time hours
IXM	---	Time minutes
IXS	---	Time seconds
IXXX	(RAINF)	Dummy label
IY	---	Flag (=), no excessive flow; @ 1, return to program control at completion of routing)
IZ	(CONTL)	Parameter indicating where control should be transfered in Program Control
	---	Index
J	---	Index
	(GATEDT)	Flag indicating (0 file closed, 1 file open)
JADDR	---	Valid raingage addresses in order scanned by RTIME
JDAY	---	Time days
JHR	---	Time hours
JIDA	---	Time days
JIHA	---	Time hours
JIMA	---	Time minutes
JISA	---	Time seconds
JJ	---	Index
JL	---	Index
JMN	---	Time minutes
JR	---	Operation table for controlling routing, combining and in line division
JSEC	---	Time seconds
JTD	---	Time days
JTH	---	Time hours
JTM	---	Time minutes
JTS	---	Time seconds
JX	---	Index
K	---	Index indicating number of times file has been searched in GATEDT
KA	---	Flag
KD	---	Time days
KDAY	(TMADD)	Days before adding
KF	---	Index
KH	---	Time-hours
KHR	(TMADD)	Hours before adding
KI	---	Index
KK	---	Number of points needed on hydrograph for diversion
KKD	---	Time days
KKM	---	Number of time intervals base flow factor should be applied
KKMM	---	Number of time intervals base flow factor should be applied first time
KKS	---	Time seconds
KM	---	Time minutes
KMIN	(TMADD)	Minutes before adding
KS	---	Time-seconds
	CHAIN 3)	Index
KSEC	(TMADD)	Seconds before adding
KTD	---	Time days
KTH	---	Hour of day
KTHH	---	Time hours
KTM	---	Time minutes; time into the past that base flow must be established
KTS	---	Time seconds
L	(CREAT 2)	Not used
	---	Index
	(TYPE 1)	*Fabridam with (ft)
LAG	---	Number of 5 minute periods flow should be lagged (Lag <0, lag time = $\lvert LAG \rvert$ x 5 minutes; Lag $\geqslant 0$, lag time = (LAG + k) x NRCHS x 5 minutes) where k = 0 if NSTRL is odd, k = 1/2 if NSTRL is even
LD	---	Time days
LDAY	(TMADD)	Days before and after adding
LF	---	*Fabridam width (ft)
LGT	---	Gate Number
LH	---	Time hours
LHR	(TMADD)	Hours before and after adding
LIST	---	*File name of constants for Chain 1 (STARTLIST)
LISTA	---	*File name of constants for Chain 3 (HYDROLIST)
LISTB	---	*File name of constants for Chain 4 (DIVERLIST)
LISTC	---	*File name of constants for Chain 5 (ROUTELIST)
LISTD	---	*File name of valid raingage addresses (RAINGAGES)
LISTX	(CREAT 2) (CHAIN 1)	*Not used
LISTY	(CREAT 2) (CHAIN 1)	*Not used
LL	---	Index

LLL	– – –	Dummy
LLOCI	– – –	Index of names (NAMES) for inlet hydrographs
LM	– – –	Time minutes
LMIN	(TMADD)	Minutes before adding, minutes after adding
LQ	– – –	Index of hydrograph related to given diversion structure
LS	– – –	Time seconds
LSEC	(TMADD)	Seconds before adding, seconds after adding
LSX	(CHAIN 1)	Time in seconds which model back dates when starting to compute real time hydrographs
	(CHAIN 4)	Time in seconds which model back dates when starting to compute diversions
M	– – –	Index
MIDAY	– – –	Model day
MIHR	– – –	Model hour
MIMIN	– – –	Model min
MISEC	– – –	Model sec
MQ	– – –	Index of maximum discharge at diversion structure
MX	– – –	Dimension limit
N	(CONTL)	Dummy parameter
	(EVNTL)	Number of points unequally spaced being past to EUNTL
	(TRAPOZ)	Number of points on hydrograph
NA	– – –	Index of orifice opening type (rectangular, crescent, segment)
	(EVNTL)	Temp index
NAM	(GATEDT)	*Name in gate setting file
NAMES	– – –	*Names of various points in system
NC	– – –	Number of catchments in system
NCC	– – –	Index of catchments
ND	– – –	Number of diversions in system
ND	– – –	Time days
NDTT	– – –	Number of points on hydrograph
NDTTB	– – –	Index of hydrograph base length
NDTTP	– – –	Index of hydrograph peak
NDTTP1	– – –	Index of hydrograph peak + 1
NG	– – –	Number of raingages in system
NH	– – –	Time hours
NM	– – –	Time minutes
NN	(EVNTL)	Number points generated so far
	(RAINF)	See NNN
NNG	– – –	Index of raingages
NNGG	– – –	Raingage index
NNN	(EVNTL)	Max number of points to be generated by EUNTL; actual number of pts generated
	(RAINF)	Number of rainfall intensities
NP	– – –	Number of points that can be used in current interval
NPA	– – –	Number of points that can be used in current interval based on one gate record for a structure
NPB	– – –	Number of points that can be used in current interval based on 2nd gate record for a structure
NPP	(EVNTL)	Accumulated value NP
NPT	– – –	Index of last point on hydrograph for which diversion is required
NP1	– – –	Index of first point on hydrograph for which a given gate and Fabridam setting holds
NP2	– – –	Index of last point on hydrograph for which a given gate and Fabridam setting holds
NQ	– – –	Index giving hydrograph number corresponding to diversion number
NQI	(CREAT 2)	No longer used
NQQ	– – –	Index of max discharge (QMAX) for Type 6 diversion structures
NRCHS	– – –	Number of subreaches section should be broken into
NSTRL	– – –	Number of pts on hydrograph to be averaged
NT	(EVNTL)	Time interval of evenly spaced points (sec)
NTER	– – –	Flag indicating (1-model is starting over start from base flow, GT. 1—add runoff to previous hydrographs)
NUMB	(RAINF)	Number of readings for each rainfall gage
NX	(RAINF)	See NNN
N1	– – –	Index
P	– – –	Wetted perimeter
Q	(CREAT 2)	Not used
	– – –	Discharge before diversion (cfs)
	(ROUTB)	Temporary storage of discharge hydrograph
QM	– – –	Max discharge at diversion

QMAX	---	Maximum discharge at various points in system, additional base flow at beginning of line from suburbs. Upper limit on discharge for bisection method
QMIN	---	Lower limit on discharge for bisection method
QN	---	Last estimate of Q2
QO	---	Discharge for which depth is desired (cfs)
QP	---	Peak discharge of hydrograph (cfs)
QPB	---	Mean daily base flow (cfs)
QPP	---	Hydrographs at all points for all times
QPPDP	---	File name of hydrographs at inlets before diversion (QPPXXDUMP) saved for future additions
QPPDX	---	File name of hydrographs at inlets after diversion (QPPDIVERT) passed to routing
QPPDZ	---	File name of hydrographs at inlets before diversion (QPPZZVERT) passed to diversion
QS	(CREAT 2)	No longer used
QXXXDP	(CREAT 2)	No longer used
QZ	---	See Q
Q2	---	Discharge to interceptor after diversion
Q2S	---	Discharge to interceptor after diversion 90" line
Q3	---	Portion of flow from 60" line
Q5	---	See Q2
R	(CHAIN 3)	Not used
	(GATEDT)	Hollerith "R"
	(EVNTL)	Values at uneven intervals
	(HYDR)	See RF
	(VALY)	Hydraulic radius
RA	---	Average rainfall intensity over watershed
RAIN	---	File name of rainfall file to be processed
RAINDP	---	No longer used
RAINDT	---	File name of rainfall intensities at even intervals for HYDR (IRAINDATA)
RDG	---	Raingage reading
REX	---	Excess intensity (in/hr)
RF	(RAINF)	Rainfall intensity for (DTT) time period
RO	(HYDR)	See RF
RR	---	Values at even intervals
S	---	Slope of interceptor at meters
	(HYDR)	Fraction of peak discharge on unit hydrograph
SAVE	(RAINF)	Temp. storage of raingage readings
SDATA	---	File name of input data file to CREAT
SIMPSN	---	Temporary value
SLOPE	---	Rainfall rate (intensity, in/hr)
SO	---	Bed slope at meters
STLOS	---	Starting value of initial loss parameter for impervious surfaces
SUM	(RAINF)	Total of valid initial rainfall readings; total of valid rainfall readings
	(CHAIN 4)	Total volume to river (cf)
T	(GATEDT)	Hollerith - operation
TB	---	Base time of unit hydrographs (secs)
TEMP	(GATEDT)	Temp file name (TEMPOFILE)
TEMPX	---	Not used
TF	---	Interpolation factor between two values
TH	---	Temporary value
TMM	(CREAT 2)	No longer used
TP	---	Time to peak of unit hydrographs (sec)
TTB	(CREAT 2)	Temp. variable ITB
TTP	(CREAT 2)	Temp. variable ITP
TTT	(CHAIN 1)	No longer used
TTTT	---	Common block name
V	---	Flow velocity (fps)
VOLA	---	Volume before diversion (cf)
VOLB	---	Volume after diversion (cf)
VOLC	---	Volume to river (cf)
X	---	Temporary value
XDECAY	(HYDR)	Loss rate recovery parameter
XI	(GATEDT)	Hollerith "I" Insert
XINTL	---	Spacing of points
XKD	---	Time days
XKH	---	Time hours
XKKD	---	Time days
XKKS	(EVNTL)	Time seconds
XKM	---	Time minutes
XKS	---	Time seconds
XL	(GATEDT)	Hollerith "L" listing
	(EVNTL)	Index
XLS	---	Time seconds

XNP	– – –	Number of points that can be used in current interval
XNT	– – –	Time interval - seconds
XRAIN	– – –	File name for real time rainfall data file (RAINRPDLY)
XSUM	– – –	Total volume to river
XXKS	(EVNTL)	Time seconds
XXX1	– – –	Raingage name
XXX2	– – –	Raingage name
X1	– – –	C1 for one structre
X10	– – –	C1-
X11	– – –	C11
X12	– – –	C12
X2	– – –	C2 for one structure
X3	– – –	C3 for one structure
X4	– – –	C4 for one structure
X5	– – –	C5 for one structure
X6	– – –	C6
X7	– – –	C7
X8	– – –	C8
X9	– – –	C9
Y	(DIV)	Depth (ft)
	– – –	Gate opening (ft)
YMAX	– – –	Max depth for bisection method
YMIN	– – –	Min depth for bisection method
YY	– – –	Gate opening (ft)
Y1	– – –	See Y (DIV)
ZZ	– – –	Volumes of hydrographs before and after diversion and vol. to river (cf)

APPENDIX C

Listing of the Model

The following is a complete listing of the model program. It is recognized that the programs in the form listed are not always accomplishing maximum efficiency. The programs have not undergone refinement but are logically correct.

```
C       PROGRAM TO CREAT MAG TAPE OF DATA FILES   27 SEP 68
       REAL LIST(2),LISTA(2),LIST3(2),LISTC(2),LISTD(2)
       REAL LISTX(2),LISTY(2)
       DIMENSION RAINDP(2),DF(19),NQ(19),NQQ(19),DIVCC(10),IIB(18),
      1ITP(15),ITB(15)
       DIMENSION QS(15),A(17),NA(17),QPPDP(2),QXXXDP(2),LLOCI(15)
       COMMON/BLOCKB/ JR(48,7),QMAX(48),D(3),S(3),QPB(15,1),AN,ALPHA(48),
      1ICONTC,LLOCI,BFFAC(24)
            COMMON/BLOCKL/L,ITQI,NQI,Q(100,4)
       COMMON/BLOCKQ/DF,NQ,NA,NQQ,A,DIVCC
      1,DIVC(17,5)
       COMMON/BLOCKH/ CZ(15,9),TP(15),TB(15),ALOSC(15,15),AREA(15),
      1FACT(15),IADDR(9),JADDR(9)
       DATA LISTA(1),LISTA(2)/5HHYDRO,4HLIST/
       DATA LISTB(1),LISTB(2)/5HDIVER,4HLIST/
       DATA LISTC(1),LISTC(2)/5HROUTE,4HLIST/
       DATA LISTD(1),LISTD(2)/5HRAING,4HAGES/
       DATA LIST(1),LIST(2)/5HSTART,4HLIST/
       DATA QXXXDP(1),QXXXDP(2)/5HQXXXX,4HDUMP/
       DATA QPPDP(1),QPPDP(2)/5HQPPXX,4HDUMP/
       DATA RAINDP(1),RAINDP(2)/5HRROXX,4HDUMP/
       DO 6 I=1,18
     6 IIB(I)=0
       CALL INPUTH(NG,NC,DT,DTT)
       CALL INPUTD(ND)
       CALL ROUTJN(TMM)
            DO 107 NCC=1,NC
            TTP=TP(NCC)/DT
            ITP (NCC)=TTP
       IF((TTP-FLOAT(ITP(NCC))).LT.0.5)GO TO 104
  103       ITP(NCC)=ITP(NCC)+1
  104       TTB=(TB(NCC)-FLOAT(ITP(NCC))*DT)/DT
            ITB(NCC)=TTB
       IF((TTB-FLOAT(ITB(NCC))).LT.0.5)GO TO 106
  105       ITB(NCC)=ITB(NCC)+1
  106       ITB(NCC)=ITB(NCC)+ITP(NCC)
   107 CONTINUE
       WRITE(5,108)ITP,ITB
   108 FORMAT(5H ITP 15I5/5H ITB 15I5)
            ITM=0
            DO 2 I=1,NC
            IF(ITB(I)-ITM)2,4,4
     4 ITM=ITB(I)
     2 CONTINJE
       CALL CLOSE (3)
       CALL CLOSE (8)
       CALL DLETE(8,LIST,I)
            CALL ENTER(8,LIST)
        WRITE(8)DTT,DT,IIB,LLOCI,ALPHA,LISTA,LISTB,LISTC,LISTD,NG,NC
       CALL CLOSE(8)
       CALL DLETE(8,LISTA,I)
            CALL ENTER(8,LISTA)
            WRITE(8)ITP,ALOSC,AREA,CZ,QPB,ITB,QPPDP,BFFAC
       CALL CLOSE(8)
      CALL DLETE(8,LISTB,I)
            CALL ENTER(8,LISTB)
      WRITE(8)ND,NC,DF,NQ,NA,NQQ,DIVC,DIVCC,A,QMAX,FACT
      CALL CLOSE(8)
      CALL DLETE(8,LISTC,I)
            CALL ENTER (8,LISTC)
      WRITE (8)JR,QMAX,D,S,AN,ICONTC,DF,DIVC,DIVCC
      CALL CLOSE(8)
      CALL DLETE(8,LISTD,I)
      CALL ENTER(8,LISTD)
      WRITE(8)IADDR,JADDR
      CALL CLOSE(8)
            STOP
      END

      SUBROUTINE INPUTD(ND)
      DIMENSION C1(17),C2(17),C3(17),C4(17),C5(17)
      COMMON/BLOCKQ/ DF(19),NQ(19),NA(17),NQQ(19),A(17),DIVCC(10)
     1 ,DIVC(17,5)
      READ(3,8)A
      ND=19
    8 FORMAT(A5)
      READ(3,1)NQ
      READ(3,1)NQQ
      READ(3,1)NA
    1 FORMAT(14I5)
      WRITE(5,2)
    2 FORMAT(31H HYDROGRAPH NO AND DIVERSION NO)
      WRITE(5,3)(NQ(I),I,I=1,19)
    3 FORMAT(     2I5,5X)
      WRITE(5,4)
    4 FORMAT(/25H INDEX OF DIVERSION POINT)
      WRITE(5,3)(NQQ(I),I,I=1,19)
      WRITE(5,5)
    5 FORMAT(/13H ORIFICE TYPE)
      WRITE(5,3)(NA(I),I,I=1,17)
      READ(3,6)C1
      READ(3,6)C2
      READ(3,6)C3
      READ(3,6)C4
      READ(3,6)C5
    6 FORMAT(7F10.5)
      READ(3,6)C6,C7,C8,C9,C10,C11,C12,C13,C14,C15
      WRITE(5,7)
    7 FORMAT(/9X,3H C1,7X,3H C2,7X,3H C3,7X,3H C4,7X,3H C5,7X,3H C6
     1,7X,3H C7,7X,3H C8,7X,3H C9,7X,4H C10,6X,4H C11,6X4H C12)
      DO 25 I=1,17
   25 WRITE(5,24)I,C1(I),C2(I),C3(I),C4(I),C5(I)
   24 FORMAT( I5,5F10.5)
    9 FORMAT( I5,5F10.5)
      WRITE(5,10)C6,C7,C8,C9,C10,C11,C12
   10 FORMAT(55X,7F10.5)
      WRITE(5,11)C13,C14,C15
   11 FORMAT(4H C13,F10.5,5X,4H C14,F10.5,4H C15,F10.5)
      READ(3,6)DF
      WRITE(5,12)
   12 FORMAT(/19H FABRIDAM DIAMETERS)
      WRITE(5,13)(I,DF(I),I=1,17)
   13 FORMAT( I5,F10.5)
      DO 99 I=1,17
      DIVC(I,1)=C1(I)
      DIVC(I,2)=C2(I)
      DIVC(I,3)=C3(I)
      DIVC(I,4)=C4(I)
   99 DIVC(I,5)=C5(I)
      DIVCC(1)=C6
      DIVCC(2)=C7
      DIVCC(3)=C8
      DIVCC(4)=C9
      DIVCC(5)=C10
      DIVCC(6)=C11
      DIVCC(7)=C12
      DIVCC(8)=C13
      DIVCC(9)=C14
      DIVCC(10)=C15
      RETURN

      END

      SUBROUTINE INPUTH(NG,NC,DT,DTT)
      DIMENSION SDATA(2)
      COMMON/BLOCKH/ CZ(15,9),TP(15),TB(15),ALOSC(15,15),A(15),FACT(15),
     1IADDR(9),JADDR(9)
C     READ QUANTITIES WHICH ARE CONSTANT FOR WHOLE PROBLEM
C     NG-NO OF RAIN GAUGES,NC-NO OF CACHMENTS,DT-TIME INTERVAL FOR
C     RAIN GAUGE READINGS,DTT-TIME INCREMENT FOR HYDROGRAPHS
   12 WRITE(6,10)
   10 FORMAT(30H ENTER NAME OF INPUT DATA FILE)
      READ(6,11)SDATA
   11 FORMAT(A5,A4)
      CALL FSTAT(3,SDATA,ISTAT)
      IF(ISTAT.EQ.0)GO TO 12
      CALL SEEK(3,SDATA)
      READ(3,2)NG,NC,DT,DTT
C     TRIANGULAR HYDROGRAPH INFORMATION,TP-TIME TO PEAK,TB-BASE TIME
      WRITE(6,14)
   14 FORMAT(27H ENTER TIME AND DATE (15A5))
      READ(6,15)A
   15 FORMAT(15A5)
      WRITE(5,16)A
   16 FORMAT(1X,15A5)
      WRITE(5,13)SDATA
   13 FORMAT(1H1,24H INPUT DATA FILE USED - ,A5,A4)
      READ(3,101)(TP(I),TB(I),I=1,NC)
      WRITE(5,102)NG,NC,DT,DTT
  101 FORMAT( 2F10.5)
  102 FORMAT(13H NO OF GAUGES,I4/16H NO OF CACHMENTS,I4/
     136H TIME INCREMENT OF RAINFALL READINGS,F10.0,5H SECS/
     230H TIME INCREMENT OF HYDROGRAPHS,F10.0,5H SECS//)
      WRITE(5,103)
  103 FORMAT(13H TIME TO PEAK,3X,10H BASE TIME,3X,8H CACH.NO)
      WRITE(5,104)(TP(I),TB(I),I,I=1,NC)
  104 FORMAT( F7.0,8X,F7.0,6X,I6)
C     LOSS COEFFS,XINLOSS-INITIAL LOSS,FC-FINAL LOSS,RATE,FO INITIAL
C     LOSS RATE,XK-EXPONENT,AA-ANTECEDANT INDEX
      READ(3,105)((ALOSC(I,J),J=1,15),I=1,NC)
  105 FORMAT( 15F5.2)
      WRITE(5,113)
  113 FORMAT(//20H LOSS RATE VARIABLES/
     193H NO. TSTLOS RECOV AX DECAY PERV PERVCF ENDK TBMC BMC STLOS TSTL
     20SP STLOSP COEF POWER ACCLOSS    /)
      WRITE(5,106)(I,(ALOSC(I,J),J=1,15),I=1,NC)
  106 FORMAT(I5,15F8.2)
      READ(3,3)(A(I),FACT(I),I=1,NC)
      WRITE(5,107)
  107 FORMAT(13H AREAS(SQ FT),5X,7HFACTORS,3X,8H CACH.NO)
      WRITE(5,108)(A(I),FACT(I),I,I=1,NC)
  108 FORMAT(1X,F10.0,6X,F10.2,I6)
C  VALID RAINGAGES ADDRESSES IN ORDER USED BY MODEL AND RTIME
      READ (3,115)(IADDR(I),JADDR(I),I=1,NG)
      WRITE (5,116)
  116 FORMAT(//54H RAINGAGE ADDRESSES IN ORDER USED BY MODEL AND SCANNED
     1  //)
      WRITE(5,114)(I,IADDR(I),JADDR(I),I=1,NG)
  114 FORMAT(2X,I5,2I7)
  115 FORMAT(2I5)
C     RAIN GAUGE PROPORTIONS FOR EACH CACHMENT
      DO 109 I=1,NC
  109 READ(3,1)(CZ(I,J),J=1,NG)
      WRITE(5,110)(J,J=1,NG)
  110 FORMAT(/23H RAIN GAUGE PROPORTIONS/ 9H GAUGE NO.I3,10(I5,5X))
C     FORMAT WILL ACCEPT UP TO 9 GAUGES
      DO 111 I=1,NC
  111 WRITE(5,112)(CZ(I,J),J=1,9),I
  112 FORMAT(2X,9F10.3,I6)
    2 FORMAT( 2I5,2F10.5)
    1 FORMAT(7F10.5)
    3 FORMAT(2F10.5)
      RETURN
      END

      SUBROUTINE ROUTJN(TMM)
      COMMON/BLOCKB/JR(48,7),QMAX(48),D(3),S(3),QPB(15,1),AN,ALPH(48),
     1ICONTC,LLOCI(15),BFFAC(24)
      READ(3,1) ICONTC
      WRITE(5,5)
      DO 2 I=1,ICONTC
      READ(3,1)(JR(I,J),J=1,7),QMAX(I),ALPH(I)
    2 WRITE(5,6)I,(JR(I,J),J=1,7),QMAX(I),ALPH(I)
    1 FORMAT(7I5,5X,F10.2,A5)
    3 FORMAT(7F10.0)
      READ(3,15)(D(I),S(I),AN,I=1,3)
   15 FORMAT(3F10.1)
      READ(3,3)QPB
      READ(3,3)BFFAC
    6 FORMAT(8I8,F10.1,A5)
    5 FORMAT(50H OPERATION TABLE,HYDROGRAPH NOS AND ROUTING CONSTS
     1/56H  OPER    HYD ENTER HYD  COMB HYD LEAVE   NSTRL       LAG
     24X,18H    NRCHS  QMAX       )
      WRITE(5,9)(D(I),S(I),AN,I=1,3)
    8 FORMAT(I5,F10.1)
    9 FORMAT(//(10X,7H DIAM =F10.2,9H  SLOPE =F10.5,
     113H MANNINGS N =F9.3))
      WRITE(5,10)
   10 FORMAT(//10H BASE FLOW)
      WRITE(5,8)(I,QPB(I,1),I=1,15)
      WRITE(5,12)(I,BFFAC(I),I=1,24)
   12 FORMAT(//5X,24HHOURLY BASE FLOW FACTORS//(5X,I4,F6.2))
      READ(3,20)LLOCI
   20 FORMAT(15I3)
      WRITE(5,11)(I,LLOCI(I),I=1,15)
   11 FORMAT(//11H NAME INDEX/(I5,I5))
      RETURN
      END
C     CHAIN 1
      REAL LIST(2),LISTA,LISTB,LISTC,LISTD,LISTX(2),LISTY(2),NAMES
      DIMENSION QPP(15,120),IIB(18),LLOCI(15),NAMES(48),LISTA(2),
     1RAIN(2),XRAIN(2),LISTB(2),LISTC(2),LISTD(2)
      DIMENSION DF(19),NQ(19),
     1NA(17),NQQ(19),DIVC(17,5),DIVCC(10),A(17),RAINDP(2),D(3),S(3)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB,LLOCI,
     1NAMES,LISTA,LISTB,LISTC,LISTD,KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN,NG,NC,QPP,
     3ITIMES(12)
      DATA LIST(1),LIST(2)/5HSTART,4HLIST/
      DATA XRAIN(1),XRAIN(2)/5HRAINR,4HPDLY/
      DATA RAINDP(1),RAINDP(2)/5HRROXX,4HDUMP/
      RAIN(1)=XRAIN(1)
      RAIN(2)=XRAIN(2)
      CALL SEEK (8,LIST)
      READ(8)DTT,DT,IIB,LLOCI,NAMES,LISTA,LISTB,LISTC,LISTD,NG,NC
      CALL CLOSE (8)
       IDT=300
      NDTT=120
      KK=85
      MISEC=0
  900 FORMAT(5X,A5,A4)
      NTER=1
      IY=0
      ICONTA=1
      ICONTB=1
      ICONTC=1
      ICONTD=1
      CALL SENSE(16,IIB(17))
      IF(IIB(17).EQ.1)GO TO 13
      WRITF(6,2)
 2    FORMAT(61H SENSE SWITCHES(ACCUM. SWS) *1-10,17 ARE USED IN THIS P
     1ROGRAM/45H  IF ON(UP) THEY HAVE THE FOLLOWING FUNCTIONS//
     250H  *1 SURPRESS PRINTOUT OF EXCESSIVE FLOW LOCATIONS/
     328H  *2 PAUSE IF EXCESSIVE FLOW/
     437H  *3 PRINTOUT RAINFALL LOSS-RATE DATA/
     536H  *4 PRINTOUT UNDIVERTED HYDROGRAPHS/
     634H  *5 PRINTOUT DIVERTED HYDROGRAPHS/
     736H  *6 PRINTOUT VOLUMES OF HYDROGRAPHS/
     853H  *7 PRINTOUT HYDROGRAPHS AT POINTS OF EXCESSIVE FLOW/
     939H  *8 PRINTOUT HYDROGRAPHS AT ALL POINTS)
      WRITE(6,4)
    4 FORMAT(40H  *9 COMPUTE UNDIVERTED HYDROGRAPHS ONLY)
      WRITE(6,5)
    5 FORMAT(
     154H  *10 COMPUTE UNDIVERTED AND DIVERTED HYDROGRAPHS ONLY)
      WRITE(6,201)
  201 FORMAT(30H  *12 SCAN REAL TIME DATA ONLY)
      WRITE(6,200)
  200 FORMAT(32H  *13 DO NOT SCAN REAL TIME DATA/
     131H  *14 RETURN TO PROGRAM CONTROL/
     238H  *15 PROCESS HISTORICAL RAINFALL FILE/
     347H  *16 SUPPRESS PRINTOUT OF PROGRAM INSTRUCTIONS)
      WRITE(6,6)
    6 FORMAT(
     241H  *17 PAUSE AT END OF LATEST COMPUTATIONS)
      WRITE(6,7)
    7 FORMAT(/
     347H SET SWITCHES TO DESIRED POSITION AND THEN TYPE)
      WRITE(6,8)
    8 FORMAT(
     427H CONTROL P  AFTER THE PAUSE )
      WRITE(6,9)
    9 FORMAT(
     538H THE SWITCHES MAY BE RESET AT ANY TIME)
      PAUSE
   12 CALL SENSE(15,IIB(16))
      IF(IIB(16).EQ.0)GO TO 26
  102 WRITE(6,22)
   22 FORMAT(1X,51H ENTER NAME OF HISTORICAL RAINFALL FILE (FILNAMEXT))
      READ (6,23)RAIN
   23 FORMAT(A5,A4)
      GO TO 25
   26 CONTINUE
      WRITE(6,10)
   10 FORMAT(1X,15HENTER REAL TIME/1X,10H HR MN DAY)
      READ(6,11) IHR,IMIN,IDAY
   11 FORMAT(2I3,I4)
      ISEC=3600*IHR+60*IMIN
C     CALL SET(ISEC,IDAY)
      MIMIN=IMIN
      MISEC=0
      MIHR=IHR
      MIDAY=IDAY
      IF(IIB(16).EQ.1) GO TO 20
   21 CONTINUE
      LSX=(NDTT-KK-1)*IDT
      CALL TMADD(MISEC,MIMIN,MIHR,MIDAY,LSX,0,0,0)
   20 TTT= 0.0
      GO TO 100
   25 CONTINUE
      CALL FSTAT(8,RAIN,ITEST)
      IF(ITEST.NE.0)GO TO 26
      WRITE(6,101)RAIN
  101 FORMAT(5X,4HFILE,2X,A5,A4,2X,23HNOT PRESENT ON DEVICE 8/)
      GO TO 102
  100 CONTINUE
      CALL CHAIN(2)
      STOP
   13 ICONTA=0
      GO TO 12
      END

      SUBROUTINE TMADD(LSEC,LMIN,LHR,LDAY,KSEC,KMIN,KHR,KDAY)
      LSEC=LSEC+KSEC
      LMIN=LMIN + KMIN
      LHR=LHR + KHR
      LDAY=LDAY + KDAY
      IF(LSEC.GE.0.AND.LSEC.LT.60)GO TO 1
      LMIN=LMIN+LSEC/60
      LSEC=LSEC-(LSEC/60)*60
      IF(LSEC.GE.0)GO TO 1
      LSEC=LSEC+60
      LMIN=LMIN-1
    1 IF(LMIN.GE.0.AND.LMIN.LT.60) GO TO 2
      LHR=LHR + LMIN/60
      LMIN=LMIN-(LMIN/60)*60
      IF(LMIN.GE.0) GO TO 2
      LMIN=LMIN + 60
      LHR=LHR-1
    2 IF(LHR.GE.0.AND.LHR.LT.24) GO TO 3
      LDAY=LDAY + LHR/24
      LHR=LHR-(LHR/24)*24
      IF(LHR.GE.0) GO TO 3
      LHR=LHR + 24
      LDAY=LDAY-1
    3 RETURN
      END


C        CHAIN2
C       GET RAINGUAGE READINGS, SET GATES, CHECK LEVELS
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),NAMES(48),
     1LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,
     3QPP(15,120),ITIMES(12)
      CALL SENSE(14,IIB(15))
      IF(IIB(15).EQ.1) GO TO 3
      CALL SENSE(13,IIB(14))
      IF(IIB(14).EQ.1)GO TO 6
      IF(ICONTD.LT.0)GO TO 6
      CALL CHAIN (9)
      STOP
    6 CONTINUE
      ICONTD=IABS(ICONTD)
      CALL SENSE(9,IIB(10))
      CALL SENSE(10,IIB(11))
      CALL SENSE(17,IIB(18))
      CALL SENSE(2,IIB(3))
      IF(IIB(16).EQ.1.AND.NTER.EQ.1) GO TO 3
      IF(IIB(18).EQ.1.OR.IIB(15).EQ.1.OR.ICONTD.EQ.2)GO TO 3
      IF(IIB(3).EQ.1.AND.IY.EQ.1)GO TO 3
      IF(IIB(10).EQ.1)GO TO 4
      IF(IIB(11).EQ.1.AND.ICONTD.EQ.4)GO TO 4
      IF(ICONTD.EQ.4)GO TO 5
      IF(ICONTD.EQ.5)GO TO 4
      CALL CHAIN(4)
      STOP
    4 CONTINUE
      ICONTD=2
      CALL RAINF
      CALL CHAIN(3)
      STOP
    3 CALL CONTL
    5 ICONTD=2
```

```
      CALL CHAIN (5)
      STOP
      END

      SUBROUTINE CONTL
      REAL NAMES,LISTA,LISTB,LISTC,LISTD
      DIMENSION BMSTL(2)
      COMMON DDT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),NAMES(48),LISTA(2),
     1LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,ICONTC,ICONTD,IC,IY,
     2MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,QPP(15,120),ITIMES(12)
      DATA BMSTL(1),BMSTL(2)/5HBMCXS,4HTLOS/
   47 WRITE(6,99)ICONTD,MIDAY,MIHR,MIMIN
   99 FORMAT(16H PROGRAM CONTROL,15H PREVIOUS CHAIN, I4,12H  MODEL TIME
     1,I5,2I3)
      ICONTD=2
   27 IF(ICONTA.EQ.0) GO TO 46
      WRITE(6,28)
   28 FORMAT(//
     146H TYPE 1 TO RESTART WITH ALL  INITIAL CONDITIONS/
     251H TYPE 2 TO RESTART COMPUTING UNDIVERTED HYDROGRAPHS/
     352H TYPE 3 TO CONTINUE COMPUTING UNDIVERTED HYDROGRAPHS/
     450H TYPE 4 TO CONTINUE COMPUTING DIVERTED HYDROGRAPHS/
     527H TYPE 5 TO CONTINUE ROUTING/
     638H TYPE 6 TO CONTINUE SCANNING REAL DATA/
     729H TYPE 7 TO CALL GATE SETTINGS/
     815H TYPE 8 TO STOP/)
      ICONTA=0
   46 CONTINUE
   45 FORMAT(12H TYPE NUMBER)
   48 READ(6,35)IZ
   35 FORMAT(I1)
      IF(IZ.LT.1.OR.IZ.GT.8) GO TO 50
      GO TO (91,92,93,94,95,96,97,98),IZ
   50 WRITE(6,40)
   40 FORMAT(18H TYPE NUMBER AGAIN)
      GO TO 48
   91 CALL CHAIN (1)
      STOP
   92 NTER=1
      WRITE(6,100)
  100 FORMAT(1X,25HENTER MODEL STARTING TIME/1X,10H HR MN DAY)
      READ(6,101)MIHR,MIMIN,MIDAY
  101 FORMAT(2I3,I4)
C      WRITE(5,102)MISEC,MIMIN,MIHR,MIDAY
C 102  FORMAT(8H TIME 1 ,4I5)
      CALL RAINF
C      WRITE(5,103)MISEC,MIMIN,MIHR,MIDAY
C 103 FORMAT(8H TIME 2 ,4I5)
      BMC=0.0
      STLOS=0.0
      CALL DLETE(7,BMSTL,N)
      CALL ENTER(7,BMSTL)
      DO 37 I=1,NC
      WRITE(7,36) BMC,STLOS,BMC,STLOS
   37 CONTINUE
   36 FORMAT(1X,4F5.2)
      WRITE(7,38) BMC
   38 FORMAT(1X,F8.1)
   CALL CLOSE(7)
   CALL CHAIN (3)
   STOP
93 NTER=2
   CALL RAINF
   CALL CHAIN (3)
   STOP
94 CALL CHAIN (4)
   STOP
95 CALL CHAIN (5)
   STOP
96 ICONTD=2
   CALL CHAIN(9)
   STOP
   GO TO 46
97 CALL GATEDT
   GO TO 47
98 STOP 777777
   END

   SUBROUTINE GATEDT
   REAL NAM
   DIMENSION GATES(2).TEMP(2).IIB(18)
   DATA GATES(1),GATES(2)/5HGATES,4HETTG/
   DATA XL,XI,R,D,E/1HL,1HI,1HR,1HD,1HE/
   DATA TEMP(1),TEMP(2)/5HTEMPO,4HFILE/
   J=0
   WRITE(6,2)
 2 FORMAT(12H GATE EDITOR/)
   CALL SENSE(16,IIB(17))
   IF(IIB(17).EQ.1) GO TO 3
   WRITE(6,4)
 4 FORMAT(43H TYPE L FOR LISTING OF PRESENT GATESETTINGS/
  154H TYPE D WITH GATE NUMBER AND TIME- TO DELETE A SETTING/
  261H TYPE I WITH GATE NUMBER, TIME AND SETTING- TO INSERT SETTING/
  361H TYPE R WITH GATE NUMBER, TIME AND SETING- TO REPLACE SETTING/
  434H TYPE E TO EXIT TO PROGRAM CONTROL/)
 3 WRITE(6,5)
 5 FORMAT(1X,24HN GT HR MN DAY X.XX X.XX)
   READ(6,6)T,IGT,IH,IM,ID,HG,HF
 6 FORMAT(A1,3I3,I4,2F5.2)
10 FORMAT(25X,26HGATE AND FABRIDAM SETTINGS//
  110X,9HDIVERSION8X4HTIME10X4HGATE4X8HFABRIDAM3X3HMAX6X3HMAX/
  211X6HNUMBER7X2HHR3X3HHMN2X3HDAY4X7HSETTING3X7HSETTING3X4HGATE
  32X8HFABRIDAM/)
   K=0
   I=0
   IF(T.EQ.XL)I=1
   IF(T.EQ.D)I=2
   IF(T.EQ.XI)I=3
   IF(T.EQ.R)I=4
   IF(T.EQ.E)I=5
   IF(I.LT.1.OR.I.GT.5)GO TO 606
   IF(I.EQ.5)GO TO 500
   IF(I.NE.1.AND.(IGT.LT.1.OR.IGT.GT.19))GO TO 606
   IF(I.NE.1.AND.(IH.EQ.0.AND.IM.EQ.C.AND.(ID.EQ.0.OR.ID.EQ.365
  1)))GO TO 606
99 GO TO (100,300,300,300,500),I
```

```
100 IF (J.EQ.1) GO TO 600
    CALL SEEK (7,GATES)
    WRITE (5,10)
 13 READ (7,11) LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    IF (LGT.EQ.20) GO TO 14
    WRITE (5,23) LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    GO TO 13
 14 CALL CLOSE (7)
    GO TO 3
300 IF (J.EQ.1) GO TO 301        6
    CALL ENTER (8,TEMP)
    CALL SEEK (7,GATES)
    J=1
301 CONTINUE
    L=0
302 READ (7,11) LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    IF (LGT.NE.IGT) GO TO 303
    NM=LM
    NH=LH
    ND=LD
    CALL TMADD (0,NM,NH,ND,0,-IM,-IH,-ID)
    IF(ND.GT.10)ND=10
    IF(ND.LT.0)ND=-10
    NM=NM + 60*NH + 1440*ND
    IF (NM) 303,304,305
303 WRITE (8,12) LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    IF (L.EQ.1) GO TO 3
    IF (LGT.EQ.20) GO TO 600
    GO TO 302
304 IF (I.EQ.2) GO TO 3
    L=1
305 IF ((I.EQ.2.OR.I.EQ.4).AND.NM.GT.0) GO TO 700
    WRITE (8,12) IGT,NAM,IH,IM,ID,HG,HF,HGMAXL,HFMAXL
    IF (L.EQ.1) GO TO 3
    L=1
    GO TO 303
500 IF (J.EQ.1) GO TO 600
    RETURN
600 K=K+1
    IF (LGT.EQ.20) GO TO 605
601 READ (7,11) LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    WRITE (8,12) LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    IF (LGT.EQ.20) GO TO 605
    GO TO 601
605 CALL CLOSE (7)
    CALL CLOSE (8)
    CALL DLETE (8,GATES,IK)
    CALL RENAM (8,TEMP,GATES,IK)
    J=0
    IF (K.EQ.2) GO TO 606
    GO TO 99
606 WRITE (6,22) T,IGT,IH,IM,ID
    GO TO 3
700 WRITE(8,12)LGT,NAM,LH,LM,LD,HGL,HFL,HGMAXL,HFMAXL
    GO TO 600
 22 FORMAT (1XA1,3I3,I4,5X32HNOT FOUND IN FILE OR OTHER ERROR)
 11 FORMAT(I3,A5,2I3,I4,4F5.2)
 12 FORMAT (1X,I3,A5,2I3,I4,4F5.2)
 23 FORMAT (11X,I3,2X,A5,2X,I3,2X,I3,I5,F9.2,F10.2,F9.2,F8.2)
    END
```

```
      SUBROUTINE EVNTL(N,NNN,NT,ISS,IMM,IHH,IDD)
C    TAKE N UNEQUALLY SPACED EVENTSRAND GENERATE NN EVENTSRR WITH SPACING D
C    STARTING AT TIME ISS,IMM,IHH,IDD.
      DIMENSION R(35),RR(35),IS(35),IM(35),IH(35),ID(35)
C     R IS AVERAGE RATE FOR LAST PERIOD UP TO TIME OF R.
      COMMON/BKTL/R,IS,IM,IH,ID,RR
C    GO BACK IN RECORD TO READING NEXT PREVIOUS TO ISS,IMM,IHH,IDD
      NN=0
      J=0
    2 J=J+1
      M=N-J+1
      IF(M.LE.0)GO TO 95
      KS=ISS
      KM=IMM
      KH=IHH
      KD=IDD
      CALL TMADD(KS,KM,KH,KD,-IS(M),-IM(M),-IH(M),-ID(M))
C     WRITE(5,198)J,M,N,KS,KM,KH,KD
      IF(KD.LT.0) GO TU 2
    5 CONTINUE
C    GO FORWARD THRU RECORD GENERATING PTS AT EVEN INTERVALS = NT(SEC)
      NA=N-1
      DO 3 I=M,NA
C     WRITE(5,198)I,J,N,ISS,IMM,IHH,IDD,NT,NN,NNN,KS,KM,KH,KD
C     WRITE(5,198)IS,IM,IH,ID
C 198 FORMAT(16I6)
      IA=I+1
      KS=-IS(I)
      KM=-IM(I)
      KH=-IH(I)
      KD =-ID(I)
      CALL TMADD(KS,KM,KH,KD,IS(IA),IM(IA),IH(IA),ID(IA))
      XKS=KS
      XKM=KM
      XKH=KH
      XKD=KD
      XLS=XKS+XKM*60.+XKH*3600.+XKD*86400.
      KS=IS(IA)
      KM=IM(IA)
      KH=IH(IA)
      KD=ID(IA)
      CALL TMADD(KS,KM,KH,KD,-ISS,-IMM,-IHH,-IDD)
C     WRITE(5,198)KS,KM,KH,KD
      IF(KD.LT.0)GO TO 3
      XKS=KS
      XKM=KM
      XKH=KH
      XKD=KD
      XNT=NT
      XKS=XKS+XKM*60.+XKH*3600.+XKD*84600.
      NP=XKS/XNT+1.
      XNP=NP
      XXKS=(XNP-1.0)*XNT
      IF((XKS-XXKS).EQ.XNT)NP=NP+1
      NPP=0
      DO 4 L=1,NP
      NPP=NPP+1
      XL=L-1
      NN=NN+1
      DR=R(IA)-R(I)
      TF=(XLS-XKS+XNT*XL)/XLS
      RR(NN)=(DR*TF)+R(I)
C     WRITE(5,11)L,DR,TF,RR(NN),NN,I,R(I),R(IA)
C  11 FORMAT(20X,I4,3F10.5,2I4,2F10.5)
      IF(NN.EQ.NNN)GO TO 12
    4 CONTINUE
   12 CONTINUE
      XNP=NPP
      XKKS=XNP*XNT
      KKD=0
C     WRITE(5,199)XKKS
C 199 FORMAT(1X,7H XKKS =,F15.2)
      IF(XKKS.LT.131000.)GO TO 16
      KKD=XKKS/86400.
      XKKD=KKD
      XKKS=XKKS-XKKD*86400.
    6 KKS=XKKS
   17 CALL TMADD (ISS,IMM,IHH,IDD,KKS,0,0,KKD)
C     WRITE  (5,10)XLS,XKS,NP,NN,KKS,M,J,I,NPP
C  10 FORMAT(2F10.1,2I6,I10,4I6)
      IF(NN.EQ.NNN)GO TO 13
    3 CONTINUE
   13 NNN=NN
      KKS=-NT
      CALL TMADD(ISS,IMM,IHH,IDD,KKS,0,0,0)
C     WRITE(5,102)ISS,IMM,IHH,IDD
C 102 FORMAT(8H TIME 6 ,5I5)
      RETURN
   16 KKS=NPP*NT
      GO TO 17
   95 NNN=0
      RETURN
      END

      SUBROUTINE RAINF
      INTEGER CHECK
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      DIMENSION RAINDT(2),SAVE(35,9),ITIME(4,35,9),IADDR(9),
     1JADDR(9),NUMB(9)
      COMMON/BKTL/R(35),IS(35),IM(35),IH(35),ID(35),RR(35)
      COMMON/TTTT/GAGE(9),RF(9)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),NAMES(48),
     1LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,
     3SAVE,ITIME,IXXX(1710),ITIMES(12)
      DATA RAINDT(1),RAINDT(2)/5HIRAIN,4HDATA/
      CALL SEEK(8,LISTD)
      CALL DLETE(7,RAINDT,I)
      CALL ENTER(7,RAINDT)
      READ(8) IADDR,JADDR
      CALL CLOSE(8)
      CALL SEEK(8,RAIN)
      DO 20 I=1,NG
   20 NUMB(I)=1
      CHECK=1
      IDTT=IDT
```

```
C      WRITE(5,505)MISEC,MIMIN,MIHR,MIDAY
C 505 FORMAT(20X,6I8)
      I=1
      NNG=NG
  201 READ(8,10)IDA,IHA,IMA,IADDA,XXX1,XXX2,RDG
   10 FORMAT(3I3,I6,A5,A2,F9.3)
      IF(IADDA.GE.7777) GO TO 210
      IF(IADDA.EQ.JADDR(NNG)) GO TO 203
  208 NNG=NNG+1
      CHECK=1
      IF(NNG.GT.NG) NNG=1
      DO 101 I=1,NG
      NNGG=I
      IF(IADDR(I).EQ.JADDR(NNG)) GO TO 11
  101 CONTINUE
   11 CONTINUE
      GAGE(NNGG)=XXX1
C      WRITE(5,500)NNG,NNGG,JADDR(NNG),GAGE(NNGG)
C 500 FORMAT(3I8,5X,A5)
      I=1
      GO TO 221
  202 READ(8,10)IDA,IHA,IMA,IADDA,XXX1,XXX2,RDG
      IF(IADDA.GE.7777) GO TO 210
      IF(IADDA.NE.JADDR(NNG)) GO TO 208
  221 IF(RDG.LE.(-.5).OR.RDG.GE.3.0) RDG=99999999.
  207 ITIME(1,1,NNGG)=IDA
      ITIME(2,1,NNGG)=IHA
      ITIME(3,1,NNGG)=IMA
      ITIME(4,1,NNGG)=0
      SAVE(1,NNGG)=RDG
      I=2
      GO TO 202
  203 IF(RDG.LE.(-.5).OR.RDG.GE.3.0) GO TO 204
      IF(SAVE(I-1,NNGG).GT.3.0) GO TO 205
      DIFF=RDG-SAVE(I-1,NNGG)
      IF(DIFF.LT.(-.02)) GO TO 204
      JIDA=-ITIME(1,I-1,NNGG)
      JIHA=-ITIME(2,I-1,NNGG)
      JIMA=-ITIME(3,I-1,NNGG)
      JISA=0
      CALL TMADD(JISA,JIMA,JIHA,JIDA,0,IMA ,IHA,IDA)
      DELT=JIDA*24+JIMA+JIMA/60+JISA/3600
      SLOPE=DIFF/DELT
      IF(SLOPE.GT.6.0) GO TO 204
      GO TO 205
  204 RDG=SAVE(I-1,NNGG)
      IF(CHECK.EQ.0) RDG=99999999.
  205 IF(CHECK.EQ.0) GO TO 206
      JIDA=-IDA
      JIHA=-IHA
      JIMA=-IMA
      CALL TMADD(0,JIMA,JIHA,JIDA,0,MIMIN,MIHR,MIDAY)
      IF(JIDA.GE.0) GO TO 207
      CHECK=0
  206 ITIME(1,I,NNGG)=IDA
      ITIME(2,I,NNGG)=IHA
      ITIME(3,I,NNGG)=IMA
      ITIME(4,I,NNGG)=0
      SAVE(I,NNGG)=RDG
      NUMB(NNGG)=I
      I=I+1
      IF(I.GT.35) GO TO 209
      GO TO 201
  209 READ(8,10)IDA,IHA,IMA,IADDA,XXX1,XXX2,RDG
      IF(IADDA.GE.7777) GO TO 210
      IF(IADDA.EQ.JADDR(NNG)) GO TO 209
      GO TO 208
  210 IF(I.LE.2) GO TO 300
      MX=35
      DO 211 I=1,NG
      N=NUMB(I)
C     WRITE(5,503)GAGE(I),NUMB(I)
C 503 FORMAT(5X,A5,5X,I5)
      DO 212 J=1,N
      R(J)=SAVE(J,I)
      ID(J)=ITIME(1,J,I)
      IH(J)=ITIME(2,J,I)
      IM(J)=ITIME(3,J,I)
      IS(J)=0
  212 CONTINUE
C     WRITE(5,501)R
C 501 FORMAT(1X,10F13.3)
      CALL SENSE(3,IIB(4))
      NN=NDTT-KK
      IF(IIB(16).EQ.1) NN=13
      IXS=MISEC
      IXM=MIMIN
      IXH=MIHR
      IXD=MIDAY
      CALL EVNTL(N,NN,IDTT,IXS,IXM,IXH,IXD)
      NUMB(I)=NN
      IF(MX.GT.NN) MX=NN
      DO 213 J=1,NN
  213 SAVE(J,I)=RR(J)
C     WRITE(5,502)NN
C     WRITE(5,501)RR
C 502 FORMAT(I10)
  211 CONTINUE
      IF(NN.EQ.MX) GO TO 214
      ISEC=(MX-1)*IDTT
      CALL TMADD(MISEC,MIMIN,MIHR,MIDAY,ISEC,0,0,0)
C     WRITE(5,505)MISEC,MIMIN,MIHR,MIDAY,ISEC
      GO TO 215
  214 MISEC=IXS
      MIMIN=IXM
      MIHR=IXH
      MIDAY=IXD
  215 SUM=0.0
C     WRITE(5,505)MISEC,MIMIN,MIHR,MIDAY
      COUNT=0.0
      NN=MX
      DO 216 I=1,NG
      IF(SAVE(1,I).GE.3.0) GO TO 216
      SUM=SUM+SAVE(1,I)
      COUNT=COUNT+1.0
  216 CONTINUE
      AVG=SUM/COUNT
      DO 217 I=1,NG
      IF(SAVE(1,I).GE.3.0) SAVE(1,I)=AVG
  217 CONTINUE
      DO 218 I=2,NN
      SUM=0.0
      COUNT=0.0
      DO 219 J=1,NG
      IF(SAVE(I,J).GE.3.0) GO TO 219
      SUM=SUM+SAVE(I,J)
      COUNT=COUNT+1.0
  219 CONTINUE
      AVG1=SUM/COUNT
      DIFF=AVG1-AVG
      DO 220 J=1,NG
      IF(SAVE(I,J).GE.3.0) SAVE(I,J)=SAVE(I-1,J)+DIFF
  220 CONTINUE
  218 AVG=AVG1
      IF(IIB(4).EQ.0) GO TO 70
      WRITE(5,71)(I,I=1,NG)
   71 FORMAT(1H1/1X,8HGAGE NO./9I9)
      DO 222 J=1,NN
  222 WRITE(5,72)(SAVE(J,I),I=1,NG)
   72 FORMAT(8X,9F9.5)
   70 NNN=NN-1
      WRITE(7) NNN,GAGE
      DO 19 J=1,NNN
      DO 18 I=1,NG
      RF(I)=(SAVE(J+1,I)-SAVE(J,I))/(DTT/3600.0)
      IF(RF(I).LT.0.0)RF(I)=0.0
   18 CONTINUE
      WRITE(7) RF
C     WRITE(5,100) RF
C 100 FORMAT(10X,9F12.6)
   19 CONTINUE
      CALL CLOSE(7)
      CALL CLOSE (8)
      RETURN
      END


C      CHAIN #3
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      DIMENSION ITP(15),ITB(15),ALOSC(15,15),CZ(15,9)
      DIMENSION QPB(15,1),QPPDP(2),R(8),JJ(85)
      DIMENSION QPP(15,120),IIB(18),LLOCI(15),NAMES(48),LISTA(2),
     1LISTB(2),LISTC(2),LISTD(2),QPPDZ(2)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB,LLOCI,
     1NAMES,LISTA,LISTB,LISTC,LISTD,KK,ICONTA,ICONTB
     2,ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,QPP,
     3 ITIMES(12)
      COMMON/BLOCKH/ITP,ITB,CZ,AR(15),BFFAC(24),QPB
      COMMON/BLOCKT/ALOSC
      DATA QPPDZ(1),QPPDZ(2)/5HQPPZZ,4HVERT/
      ICONTD=3
      DO 203 I=1,KK
  203 JJ(I)=-(NDTT-KK)+I
      CALL SEEK (8,LISTA)
      READ (8) ITP,ALOSC,AR,CZ,QPB,IIB,QPPDP,BFFAC
      CALL CLOSE(8)
C     READ RAIN GAUGES AND CALCULATE HYDROGRAPHS
```

```
          IF(NTER-1)100,101,100
  101 CALL DLETE(8,QPPDP,IK)
      CALL ENTER(8,QPPDP)
      KTM=-(NDTT-KK)*(IDT/60)
      KTS=KTHH=KTD=0
      CALL TMADD(KTS,KTM,KTHH,KTD,MISEC,MIMIN,MIHR,MIDAY)
      KKMM=(60-KTM)/(IDT/60)
      DO 71 I=1,NC
      KKM=KKMM
      KTH=KTHH+1
      KS=1
   32 KF=KS+KKM-1
      DO 30 KI=KS,KF
      QPP(I,KI)=QPB(I,1)*BFFAC(KTH)
      IF(KI.EQ.120) GO TO 31
   30 CONTINUE
      KS=KF+1
      KKM=(3600/IDT)
      KTH=KTH+1
      IF(KTH.GE.25)KTM=KTH-24
      GO TO 32
   31 CONTINUE
   71 CONTINUE
      WRITE (8)QPP
          CALL CLOSE (8)
  100 CONTINUE
  112 CALL HYDR(NG,NC)
      CALL DLETE(8,QPPDZ,IK)
      CALL ENTER (8,QPPDZ)
      WRITE(8)QPP
      CALL CLOSE (8)
      CALL DLETE(8,QPPDP,IK)
      CALL ENTER(8,QPPDP)
      WRITE(8)QPP
      CALL CLOSE (8)
      CALL SENSE(4,IIB(5))
      IF(IIB(5).EQ.0)GO TO 80
      WRITE(5,75)MIHR,MIMIN,MIDAY
   75 FORMAT(//1X,22HUNDIVERTED HYDROGRAPHS/
     139H POINT  0 REPRESENTS PRESENT MODEL TIME,2X,2I3,I4,5X,
     232HPOINTS ARE AT 5 MINUTE INTERVALS)
      DO 74 I=1,NC
      LL=LLOCI(I)
      WRITE(5,72)NAMES(LL),I
      WRITE(5,73)(JJ(J),QPP(I,J),J=1,KK)
   72 FORMAT(//1X,A5,15H HYDROGRAPH NO.,I5)
   73 FORMAT(1X,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,
     1I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1)
   74 CONTINUE
   80 CONTINUE
      CALL CHAIN(2)
      STOP
      END

      SUBROUTINE HYDR
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      DIMENSION QPP(15,120),TEMPX(2),QPPDP(2),XDECAY(15)
      DIMENSION ITP(15),ITB(15),RAINDT(2),GAGE(9)
      DIMENSION RO(9),RF(9),CZ(15,9),R(9),BMSTL(2)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15)
     1,NAMES(48),LISTA(2),LISTB(2),LISTC(2),LISTD(2),
     2KK,ICONTA,ICONTB,ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY
     3,MISEC,RAIN(2),NG,NC,QPP
      COMMON/BLOCKH/ITP,ITB,CZ,A(15),BFFAC(24),QPB(15,1)
      COMMON/BLOCKT/ALOSC(15,15)
      DATA BMSTL(1),BMSTL(2)/5HBMCXS,4HTLOS/
      DATA RAINDT(1),RAINDT(2)/5HIRAIN,4HDATA/
      DATA QPPDP(1),QPPDP(2)/5HQPPXX,4HDUMP/
      DATA TEMPX(1),TEMPX(2)/5HTEMPO,4HRARY/
C     SETINITIAL RAIN GAUGE READING
      CALL SEEK(7,RAINDT)
   98 FORMAT(18H READINGS AND TIME,9F10.5,5X,2I3,I4/)
C
C     TIME
C     TTT-TIME AFTER START OF STROM,NTER-CORRESPONDING RAINFALL
C     INCREMENT
C     NO
      CALL SEEK(8,BMSTL)
      DO 798 I=1,NC
      READ(8,799)ALOSC(I,9),ALOSC(I,10),ALOSC(I,12),ALOSC(I,15)
      XDECAY(I)=ALOSC(I,4)**(.25)
  799 FORMAT(4F5.2)
  798 CONTINUE
      READ(8,796)ACCUM
  796 FORMAT(F8.1)
      CALL CLOSE(8)
      IDTT=IDT
      CALL SENSE(3,IIB(4))
      IF(IIB(4).EQ.0)GO TO 200
      WRITE(5,201)RAIN,(I,I=1,NG)
  201 FORMAT(1H1/51H RAINGAGE READINGS AT 5 MINUTE INTERVALS IN (IN/HR)
     134H FOR INTERVAL ENDING AT TIME SHOWN,10X,16HRAINFALL FILE - ,
     2A5,A4//5X,8HGAGE NO.,3X,9I10,8X,9HHR MN DAY)
  200 CONTINUE
C     READ RAINGAUGES
      READ(7)IR,GAGE
      CALL SEEK(8,QPPDP)
      READ (8)QPP
      DO 129 IRI=1,IR
      ACCUM=ACCUM+DT
  199 READ (7)R
      IF(IIB(4).EQ.0)GO TO 114
      JSEC=-(IR-IRI)*IDTT
      JMN=0
      JHR=0
      JDAY=0
      CALL TMADD(JSEC,JMN,JHR,JDAY,MISEC,MIMIN,MIHR,MIDAY)
      WRITE(5,97)(GAGE(I),I=1,NG)
   97 FORMAT(/18X,9(5X,A5))
      WRITE(5,98)(R(I),I=1,9),JHR,JMN,JDAY
  114 DO 4 NGG=1,NG
          RF(NGG)=R(NGG)
          RO(NGG)=R(NGG)
    4 CONTINUE
          DO 21 NCC=1,NC
      ALOSC(NCC,4)=1.0
      IF(ACCUM.LT.21600.0)GO TO 797
      ALOSC(NCC,4)=XDECAY(NCC)
      ACCUM=ACCUM-21600.0
  797 RA=0.0
      DO 6 NGG=1,NG
          RA=RA+CZ(NCC,NGG)*RF(NGG)
    6 CONTINUE
      ITT=NDTT-1
      DO 700 IT=1,ITT
      IS=IT+1
  700 QPP(NCC,IT)=QPP(NCC,IS)
      JTM=KK*(IDT/60)
      JTS=JTH=JTD=0
      CALL TMADD(JTS,JTM,JTH,JTD,MISEC,MIMIN,MIHR,MIDAY)
      JTH=JTH+1
       QPP(NCC,NDTT)=QPB(NCC,1)*BFFAC(JTH)
      CALL SLOS(RA,REX,NCC,DT,IIB(4))
          QP=REX*A(NCC)/(3600.0*12.0)*DT*2.0/(FLOAT(ITB(NCC)-1)*DT)
          NDTTP=1+ITP(NCC)
          NDTTB=1+ITB(NCC)
          DO 8 I=1,NDTTP
      IT=I+(NDTT-KK)-1
      S=FLOAT(I-1)/FLOAT(ITP(NCC))
      QPP(NCC,IT)=QPP(NCC,IT)+S*QP
    8 CONTINUE
          NDTTP1=NDTTP+1
          DO 9 I=NDTTP1,NDTTB
      IT=I+(NDTT-KK)-1
      S=FLOAT(NDTTB-I)/FLOAT(ITB(NCC)-ITP(NCC))
      QPP(NCC,IT)=QPP(NCC,IT)+S*QP
    9 CONTINUE
   21 CONTINUE
  129 CONTINUE
      CALL CLOSE(8)
  130 CONTINUE
      CALL CLOSE(7)
      NTER=2
      CALL DLETE(8,BMSTL,LLL)
      CALL ENTER(8,BMSTL)
      DO 795 I=1,NC
      WRITE(8,794)ALOSC(I,9),ALOSC(I,10),ALOSC(I,12),ALOSC(I,15)
  794 FORMAT(1X,4F5.2)
  795 CONTINUE
      WRITE(8,793)ACCUM
  793 FORMAT(1X,F8.1)
      CALL CLOSE(8)
          RETURN
          END


      SUBROUTINE SLOS(R,REX,I,DT,II)
      COMMON/BLOCKT/TSTLOS(15),RECOV(15),AX(15),DECAY(15),XIMPER(15),
     1XIMPCF(15),ENDK(15),TBMC(15),BMC(15),STLOS(15),TSTLSP(15),
     2STLOSP(15),COEF(15),POWER(15),ACLOSS(15)
      RA=R*DT/3600.
C     IMPERVIOUS AREA
      Z=STLOS(I)
      STLOS(I)=STLOS(I)+RA
      IF(STLOS(I).GT.TSTLOS(I)) GO TO 3
      X=0.0
      GO TO 19
    3 X=STLOS(I)-TSTLOS(I)
      STLOS(I)=TSTLOS(I)
   19 XILIMP=STLOS(I)-Z
      XLSCOF=1.0/(COEF(I)*EXP(POWER(I)*ACLOSS(I)))
      IF(XLSCOF.GT.1.0) XLSCOF=1.0
      XLSIMP=X*XLSCOF
      REXIMP=X-XLSIMP
      TLSIMP=XILIMP+XLSIMP
      ACLOSS(I)=ACLOSS(I)+TLSIMP
C     PERVIOUS AREA
      W=STLOSP(I)
      STLOSP(I)=STLOSP(I)+RA
      IF(STLOSP(I).GT.TSTLSP(I)) GO TO 5
      Y=0.0
      GO TO 4
    5 Y=STLOSP(I)-TSTLSP(I)
      STLOSP(I)=TSTLSP(I)
    4 XILPRV=STLOSP(I)-W
      SLOSX=ENDK(I)+AX(I)*((TBMC(I)-BMC(I))/TBMC(I))**0.70
      POTLSS=SLOSX*DT/3600.
      ACTLSS=POTLSS
      IF(ACTLSS.GT.Y) ACTLSS=Y
      REXPRV=Y-ACTLSS
      TLSPER=ACTLSS+XILPRV
      BMC1=BMC(I)
      BMC(I)=BMC(I)+TLSPER
      BASLSS=TLSPER*XIMPER(I)+TLSIMP*(1.0-XIMPER(I))
      BSEXCS=(REXPRV)*XIMPER(I)+REXIMP*(1.0-XIMPER(I))
      REX=BSEXCS*3600./DT
      IF(BMC(I).GT.TBMC(I))BMC(I)=TBMC(I)
      IF(II.EQ.0)GO TO 14
      IF(I.GT.1)GO TO 11
      WRITE(5,12)
   12 FORMAT(128H         I    RAIN    ISTLOS    PSTLOS   IINLOS PINLOS  ILOSC
     1OE PPOTLOS    ILOSS  PLOSS    IEXS       PEXS    BASLOS    BASEXS     BMC
     2ACCLOSS,//)
   11 WRITE(5,13)I,RA,STLOS(I),STLOSP(I),XILIMP,XILPRV,XLSCOF,POTLSS,
     1XLSIMP,ACTLSS,REXIMP,REXPRV,BASLSS,BSEXCS,BMC(I),ACLOSS(I)
   13 FORMAT(I6,2X,15F8.4)
   14 RETURN
      END

C     CHAIN4
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      DIMENSION QPP(15,120),IIB(18),LLOCI(15),NAMES(48),LISTA(2),
     1LISTB(2),LISTC(2),LISTD(2),DF(19),NQ(19),NA(17),NQQ(19),
     3DIVC(17,5),DIVCC(10),QPPDZ(2),FACT(15),
     4QMAX(48),QPPDX(2),ZZ(6,15),SS(6)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB,LLOCI,NAMES,
     1LISTA,LISTB,LISTC,LISTD,KK,ICONTA,ICONTB,ICONTC,ICONTD,
     2IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,QPP,ITIMES(12)
      COMMON/DIVE/DF,NQ,NA,NQQ,DIVC,   QMAX,FACT
      COMMON/TY/X1,X2,X3,X4,X5,DIVCC,JJ(85)
      EQUIVALENCE (DIVC(1),ZZ(1,1)),(DF(1),SS(1))
      DATA QPPDX(1),QPPDX(2)/5HQPPDI,4HVERT/
      DATA QPPDZ(1),QPPDZ(2)/5HQPPZZ,4HVERT/
      ICONTD=4
      DO 200 I=1,KK
  200 JJ(I)=-(NDTT-KK)+I
      CALL SEEK (8,LISTB)
      READ(8)ND,NC,DF,NQ,NA,NQQ,DIVC,DIVCC,FACT,SUM,SUM,QMAX,FACT
      CALL CLOSE(8)
      CALL SEEK(8,QPPDZ)
      READ(8)QPP
      CALL CLOSE(8)
      DO 32 I=1,ND
      IF(NQ(I).GE.16)GO TO 32
      CALL DIV(I)
      CALL SENSE(14,IIB(15))
      IF(IIB(15).EQ.1)GO TO 500
   32 CONTINUE
      CALL SENSE(5,IIB(6))
      IF(IIB(6).EQ.0) GO TO 42
      WRITE(5,201)MIHR,MIMIN,MIDAY
      DO 42 I=1,NC
      LL=LLOCI(I)
      WRITE(5,72)NAMES(LL),I
      WRITE(5,73)(JJ(J),QPP(I,J),J=1,KK)
   42 CONTINUE
      CALL DLETE(3,QPPDX,I)
      CALL ENTER(3,QPPDX)
      DO 35 I=1,NC
      DO 34 K=1,NDTT
   34 QPP(I,K)=QPP(I,K)*FACT(I)
   35 CONTINUE
      WRITE(3)QPP
      CALL CLOSE(3)
      CALL SENSE(5,IIB(6))
      IF(IIB(6).EQ.0)GO TO 210
      WRITE(5,201)MIHR,MIMIN,MIDAY
  201 FORMAT(//1X,20HDIVERTED HYDROGRAPHS/
     138H POINT 0 REPRESENTS PRESENT MODEL TIME,I6,I3,I4,
     25X,31HDISCHARGE AT 5 MINUTE INTERVALS)
      DO 71 I=1,NC
      K=LLOCI(I)
      WRITE (5,72) NAMES(K),I
   72 FORMAT(//1XA5,17H   HYDROGRAPH NO.,I5)
      WRITE (5,73)( JJ(J),QPP(I,J),J=1,KK)
   71 CONTINUE
   73 FORMAT(1X,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,
     1I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1)
  210 CALL SENSE(6,IIB(7))
      IF(IIB(7).EQ.0)GO TO 211
C       ******CALC VOLUMES*********
      DO 10 I=1,6
   10 SS(I)=0.0
      CALL SEEK (8,QPPDZ)
      K=1
  302 CONTINUE
      READ(8)QPP
      CALL CLOSE(8)
      DO 300 I=1,NC
      ZZ(K,I)=TRAPOZ(KK,DTT,I)
  300 CONTINUE
```

```
      IF(K.EQ.2)GO TO 303
      CALL SEEK(8,QPPDX)
      K=K+1
      GO TO 302
  303 K=K+1
      DO 44  I=1,NC
   44 ZZ(1,I)=ZZ(1,I)*FACT(I)
      WRITE(5,307)
  307 FORMAT(13H INLET INDEX ,18H LUMPED INLET VOL ,
     118H  LUMPED DIV VOL  ,18H LUMPED RIVER VOL ,
     118H    INLET VOL     ,18H   DIVERTED VOL   ,14H    RIVER VOL )
      DO 304 I=1,NC
      ZZ(K,I)=ZZ(1,I)-ZZ(2,I)
      ZZ(4,I)=ZZ(1,I)/FACT(I)
      ZZ(5,I)=ZZ(2,I)/FACT(I)
      ZZ(6,I)=ZZ(3,I)/FACT(I)
      DO 11 J=1,6
      SS(J)=SS(J)+ZZ(J,I)
   11 CONTINUE
  304 WRITE(5,305)I,(ZZ(J,I),J=1,6)
  305 FORMAT(5XI2,10XF10.0,8XF10.0,8XF10.0,8XF10.0,8XF10.0,
     18XF10.0)
      WRITE(5,306)(SS(J),J=1,6)
  306 FORMAT(17H TOTAL VOLUME CF F10.0,8XF10.0,8XF10.0,
     18XF10.0,8XF10.0,8XF10.0)
  308 FORMAT(17H TOTAL VOLUME MG 4XF8.2,10XF8.2,10XF8.2,
     110XF8.2,10XF8.2,10XF8.2)
      DO 12 I=1,6
      SS(I)=SS(I)*7.48/1000000.0
   12 CONTINUE
      WRITE(5,308)(SS(J),J=1,6)
  211 CONTINUE
  500 CALL CHAIN(2)
      STOP
      END


      SUBROUTINE DIV(ND)
C     AT EACH INLET POINT THE HYDROGRAPH IS CALCULATED FOR THE AMOUNT OF
C     RAIN WHICH HAS FALLEN.THIS SUBROUTINE THEN DETERMINES THE AMOUNT
C     OF THE HYDROGRAPH WHICH ACTUALLY FLOWS TO THE MAIN INTERCEPTOR AT
C     THAT POINT.(I.E. THE FLOOD WAVE WHICH IS THEN ROUTED THROUGH THE
C     SYSTEM)ND-DIVERSION NO,                 DF-DIAM OF PIPE IN WHICH
C     FABRIDAM IS FIXED,H-HGHT OF FABRIDAM,NQ-NO OF HYDROGRAPH FOR
C     DIVERSION ND,NT-TIME NO,NA-NO DESIGNATING GEOMETRICAL SHAPE OF
C     ORIFICE,NQQ-INDEX OF POINT AT WHICH FLOW IS DIVERTED(EG METERS),
C     ALSO INDEX OF INFLOW POINT FOR ST PETER DIVERSION
C
C
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      DIMENSION C1(17),C2(17),C3(17),C4(17),C5(17)
      DIMENSION IIB(18),LLOCI(15),NAMES(48),LISTA(2),LISTB(2),
     1LISTC(2),LISTD(2)
      DIMENSION DF(19),NQ(19),NA(17),QPP(15,120),NQQ(19)
C     FOR SPECIFIED DIVERSION STRUCTURES GO TO APPROPRIATE SUBROUTINE
      COMMON/TY/X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,X11,X12,C13,C14,C15
      COMMON DTT,NDTT,IDT,NTER,DT,IIB,LLOCI,NAMES,
     1LISTA,LISTB,LISTC,LISTD,KK,ICONTA,ICONTB,ICONTC,ICONTD,
     2IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,QPP
```

```
      COMMON/DIVE/DF,NQ,NA,NQQ,C1,C2,C3,C4,C5,QMAX(48),FACT(15)
      X1=C1(ND)
      X2=C2(ND)
      X3=C3(ND)
      X4=C4(ND)
      X5=C5(ND)
      IDTM=IDT/60
      NP2=0
      NPT=KK
      IS=0
      IMINH=MIMIN
      IHRH=MIHR
      IDAYH=MIDAY
      LSX=-(NDTT-KK-1)*IDT
      CALL TMADD(IS,IMINH,IHRH,IDAYH,LSX,0,0,0)
      GO TO (1,1,5,1,1,4,1,6,1,1,1,1,2,1,7,7,7,6,6),ND
C     THE STATEMENT NOS IN THE PRECEDING STATEMENT CORRESPOND TO THE
C     TYPE OF THE DIVERSION EQN.IF DIFFERENT DIVERSION EQNS ARE NEEDED
C     THESE CAN BE ADDED,STARTING WITH STATEMENT NOS LESS THAN 100
    1 LQ=NQ(ND)
   24 CALL FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NP)
      IF(NPT.LE.NP)GO TO 20
      NP1=NP2+1
      NP2=NP
      GO TO 21
   20 NP1=NP2+1
      NP2=KK
   21 DO 22 K=NP1,NP2
  101 CALL TYPE1(ND,DF(ND),HFF,HGG,QPP(LQ,K),Q2,NA(ND))
      QPP(LQ,K)=Q2
   22 CONTINUE
      IF(NP2.EQ.KK)GO TO 23
      NPT=KK-NP2
      NP=NP*IDTM+IDTM
      CALL TMADD(0,IMINH,IHRH,IDAYH,0,NP,0,0)
      GO TO 24
   23 CONTINUE
      GO TO 100
    2 LQ=NQ(ND)

   34 CALL FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NPA)
      CALL FABGTS(19,IMINH,IHRH,IDAYH,HGGG,HFFF,NPB)
      IF(NPA.GT.NPB)GO TO 35
      NP=NPA
      GO TO 36
   35 NP=NPB
   36 IF(NPT.LE.NP)GO TO 30
      NP1=NP2+1
      NP2=NP
      GO TO 31
   30 NP1=NP2+1
      NP2=KK
   31 DO 32 K=NP1,NP2
      CALL TYPE2(ND,QPP(LQ,K),HGG,HGGG,Q2)
      QPP(LQ,K)=Q2
```

```
32 CONTINUE
   IF(NP2.EQ.KK)GO TO 33
   NPT=KK-NP2
   NP=NP*IDTM+IDTM
   CALL TMADD(0,IMINH,IHRH,IDAYH,0,NP,0,0)
   GO TO 34
33 CONTINUE
   GO TO 100
 4 LQ=NQ(ND)
44 CALL FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NPA)
   CALL FABGTS(18,IMINH,IHRH,IDAYM,HGGG,HFFF,NPB)
   IF(NPA.GT.NPB)GO TO 45
   NP=NPA
   GO TO 46
45 NP=NPB
46 IF(NPT.LE.NP)GO TO 40
   NP1=NP2+1
   NP2=NP
   GO TO 41
40 NP1=NP2+1
   NP2=KK
41 DO 42 K=NP1,NP2
   CALL TYPE4(ND,QPP(LQ,K),Q2,HGG,HFF,HGGG,HFFF,
  1DF(ND),DF(18))
   QPP(LQ,K)=Q2
42 CONTINUE
   IF(NP2.EQ.KK)GO TO 43
   NPT=KK-NP2
   NP=NP*IDTM+IDTM
   CALL TMADD(0,IMINH,IHRH,IDAYH,0,NP,0,0)
   GO TO 44
43 CONTINUE
   GO TO 100
 5 LQ=NQ(ND)
54 CALL FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NP)
   IF(NPT.LE.NP)GO TO 50
   NP1=NP2+1
   NP2=NP
   GO TO 51
50 NP1=NP2+1
   NP2=KK

51 DO 52 K=NP1,NP2
   Y=0.0
   CALL TYPE5(ND,QPP(LQ,K),DF(ND),HFF,C13,C14,HGG,Y,
  1Q2,C15)
   QPP(LQ,K)=Q2


52 CONTINUE
   IF(NP2.EQ.KK)GO TO 53
   NPT=KK-NP2
   NP=NP*IDTM+IDTM
   CALL TMADD(0,IMINH,IHRH,IDAYH,0,NP,0,0)
   GO TO 54
53 CONTINUE
   GO TO 100
```

```
    6 LQ=NQ(ND)
      MQ=NQQ(ND)
      DO 181 K=1,KK
      IF(QPP(LQ,K).LT.QMAX(MQ)/FACT(LQ))GO TO 181
      QPP(LQ,K)=QMAX(MQ)/FACT(LQ)-0.01
  181 CONTINUE
      GO TO 100
    7 RETURN
C   64 CALL FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NP)
      IF(NPT.LE.NP)GO TO 60
      NP1=NP2+1
      NP2=NP
      GO TO 61
   60 NP1=NP2+1
      NP2=KK
   61 DO 62 K=NP1,NP2
C     CALL TYPE7(ND,Y,HGG,C1(ND),C2(ND),Q)
   62 CONTINUE
  100 RETURN
C     TYPE1-FABRIDAM AND ORIFICE
C     TYPE2-SIDE WEIR AT CAMDEN
C     TYPE4-DOUBLE GATE AND 2 FABRIDAMS AT EUSTIS
C     ST PETER KELLOGG DIVERSION-TYPE5
C     TYPE6-RANDOLPH
C     TYPE7-DIVERSIONS AT METERS
      END
```

```
      SUBROUTINE TYPE1(NC,DF,H,HG,Q   ,Q2,NA)
C     FABRIDAM AND RECTANGULAR ORIFICE
C     NC-CACHMENT NO,DF-DIAM OF PIPE IN WHICH FABRIDAM IS FIXED,H-HGHT
C     OF FABRIDAM,Q  -FLOW RATE,Q2-FLOW DIVERTED TO SEWER,NA-AREA TYPE
C     EQN F=Q-Q2-C1*L*(C2*Q**2/AO**2+HG/2-H+C5)**C3
C     C1-COEFF OF DISCHARGE OF FABRIDAM,L-LGTH OF CREST OF FABRIDAM,
C     C2=1/2*32.2*CD WHERE CD IS COEFF OF DISCHARGE OF ORIFICE,C5-ELE-
C     VATION OF ORIFICE INVERT      ,C3-EXPONENT OF DAM DISCHARGE EQN,
C     AO-ORIFICE AREA,C4-WIDTH OF ORIFICE GATE    ORIGIN IS INVERT OF
C     PIPE AT FABRIDAM
      REAL L
      COMMON/TY/C1,C2,C3,C4,C5,X6,X7,X8,X9,X10,X11,X12
C     WRITE(5,30)NC,DF,H,HG,Q,C1,C2,C3,C4,C5,NA
C  30 FORMAT(31H NC,DF,H,HG,Q,C1,C2,C3,C4,C5,NA I5,3F8.5,F8.2,5F8.5,I5)
  100 GO TO (21,22,23),NA
   21 AO=C4*HG
      GO TO 24
   22 AO=AREA(C4,HG)
```

```
      GO TO 24
C3          WRITE(6,201) NC,C4,HG
   23 CONTINUE
C01         FORMAT(2X,I2,2F10.5)
      AO=CRES(C4,HG)
C02         FORMAT(2X,F10.5)
   24 IF(AO.LE.0.0)AO=0.00001
      IF(Q.LE.0.00)Q=0.000001
      IF(C2*Q**2./AO**2+HG/2.-H+C5)11,11,2
    2 QMAX=Q
      L=TOP(DF,H)
      QMIN=0
      K=1
    3 Q2=(QMAX+QMIN)/2.
      IF(Q2.LE.0.0)Q2=0.00001
      BB=C2*Q2**2/AO**2+HG/2.-H+C5
      IF(BB.LE.0.0)BB=0.0000001
    5 F=Q-Q2-C1*L*BB**C3
      CALL BISECC(F,Q2,QMAX,QMIN,K,NC,QN)
C     WRITE(5,40)F,Q2,QMAX,QMIN,K,NC,QN,BB,L,AO
C  40 FORMAT(31H F,Q2,QMAX,QMIN,K,NC,QN,BB,L,AO F8.5,3F8.2,2I4,F8.2,
C    1F10.6,2F8.3)
  101 IF(K-50)3,1,1
   11 Q2=Q
    1 RETURN
      END

      SUBROUTINE TYPE2(NC,Q,H5,H6,Q5)
C     DIVERSION AT CAMDEN AVE BRIDGE
C     NC-CACHMENT NO,Q-FLOW APPROACHING DIVERSION,C1-COEFF OF DISCHARGE
C     OF SIDE CHANNEL WEIR,C2-LGTH OF SIDE CHANNEL WEIR,C3-COEFF OF
C     DISCHARGE OF GATES(ASSUMED EQUAL),A5-AREA OF ARIFICE DISCHARGING
C     TO INTERCEPTOR,C4-ELEVATION OF WEIR CREST A6-AREA OF BYPASS
C     ORIFICE
C     Q5-DISCHARGE TO INTERCEPTOR
C     EQN  F=Q-C1*C2*(Q5**2/(2*32.2*C3**2*A5)-C4)**1.5-Q5(A6/A5+1)
C     H5-HGAT OF GATE OPENING,IN INTERCEPTOR LINE,H6-HGHT OF GATE OPEN-
C     ING IN BYPASS LINE(BOTH GATES 4FT DIAM)
      REAL LF
      COMMON/TY/C1,C2,C3,C4,X5,X6,X7,X8,X9,X10,X11,X12
      A5=AREA(4.,H5)
      A6=AREA(4.,H6)
      IF(A5.LE.0.0)A5=0.0001
      IF(Q.LE.0.0)Q=0.001
      IF(Q**2.0/(2.0*32.2*C3**2.0*A5**2.0)-C4)1,1,2
    1 Q5=Q/(A6/A5+1.0)
      RETURN
    2 QMAX=Q
      QMIN=0
      K=1
    3 Q5=(QMAX+QMIN)/2.
      BB=(Q5/(C3*A5))**2/64.4-C4
      IF(BB)5,6,6
    5 BB=0.000000001
    6 F=Q-C1*C2*BB**1.5-Q5*(A6/A5+1.)
      CALL BISECC(F,Q5,QMAX,QMIN,K,NC,QN)
      IF(K-50)3,4,4
    4 RETURN
      END
      SUBROUTINE TYPE4(ND,Q,Q2,H,HF,      HA,HFA,DF,DFA)
      REAL LF
      COMMON/TY/C1,C2,C3
C     EUSTIS DIVERSION
C     Q-APPROACHING FLOW,Q2-DIVERTED FLOW,C1-COEFF OF DISCHARGE OF
C     FABRIDAM,C2-EXPONENT OF FABRIDAM DISCHARGE,H-HGHT OF GATE,HF-HGHT
C     OF FABRIDAM,EQN F=C1*LF*(Q2**2/(32.2*A**2)+H/2-MF)**C2
C     A-AREA OF ORIFICE,LF-LGHT OF FABRIDAM
C     THE ABOVE APPLIES TO DIVERSION OF 90INCH PIPE.THE SAME EQN APPLIES
C     TO DIVERSION OF 60INCH PIPE.THE LETTERA REFERS TO THE LATTER DIVER
C     SION
C     Q3-APPROACHING FLOW FOR 60INCH PIPE(ASSUMED TO BE C3*Q
C
C
C
C
C     WRITE(5,400)ND,Q,C1,C2,H,HF,C3,HA,HFA,DF,DFA
C 400 FORMAT(39H TYPE4 ND,Q,C1,C2,H,HF,C3,HA,HFA,DF,DFA/I5,10F10.5)
      Q3=C3*Q
      Q=Q*(1.0-C3)
      KA=0
    7 LF=TOP(DF,HF)
      A=CRES(3.,H)
C     WRITE(5,401)LF,A
C 401 FORMAT(11H TYPE4 LF,A,2F10.5)
      IF(Q**2/(32.2*A**2)+H/2.-HF)1,1,2
    2 QMAX=Q
      QMIN=0.
      K=1
    3 Q2=(QMAX>QMIN)/2.
      BB=Q2**2/(32.2*A**2)+H/2.-HF
      IF(BB)30,8,8
   30 BB=0.000001
    8 F=Q-C1*LF*BB**C2
C     WRITE(5,402)Q2,F,K
C 402 FORMAT(13H TYPE4 Q2,F,K,2F10.5,I5)
      CALL BISECC(F,Q2,QMAX,QMIN,K,ND,QN)
      IF(K-50)3,4,4
    1 Q2=Q
    4 IF(KA)5,5,6
    5 Q2S=Q2
C     60 INCH DIVERSION
      HSAVE=H
      HFSAVE=HF
      DFF=DF
      DF=DFA
      Q=Q3
      H=HA
      HF=HFA
      KA=1
      GO TO 7
    6 Q2=Q2+Q2S
      H=HSAVE
      HF=HFSAVE
      DF=DFF
      RETURN
      END
      SUBROUTINE TYPES(ND,Q,DF,HF
     1,C13,C14,H,Y1,Q5,C15)
      REAL LF
      COMMON/TY/C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12
C     ST PETER KELLOGG
C     NC-CACHMENT NO.Q-APPROACHING FLOW,C1-COEFF OF DISCHARGE OF WEIR AT
C     A,C2-LENGTH OF WEIR AT A,C3-COEFF OF DISCHARGE OF ORIFICE AT D,
C     C7-AREA OF ORIFICE AT D,C4-COEFF OF DISCHARGE OF FABRIDAM,LF-LGTH
C     OF FABRIDAM CREST,C6-EXPONENT FOR FABRIDAM DISCHARGE EQN
C     1ST DIVERSION EQN
C     F=Q-Q2-C1*C2*(Q2**2/(2*32.2*C3**2*C7**2-5)**1.5-(4*LF*(Q2**2/2*
C     32.2*C3**2*C7**2-HF)**C6
C     Q-APPROACHING FLOW RATE,Q2-FLOW GOING TO 2ND DIVERSION,DF-DIAM OF
C     FABRIDAM PIPE,HF-HGHT OF FABRIDAM
C
C     2ND DIVERSION
C     C9-COEFF OF DISCHARGE OF SIDE WEIR,C8-HGHT OF UPPER WEIR CREST,
C     C10-LGTH OF LOWER SIDE WEIR CREST,C11-COEFF OF DISCHARGE OF
C     ORIFICE,C12-HGHT OF LOWER WEIR CREST,C13-DIFF IN ELEV BETWEEN
C     ORIFICE AND INTERCEPTOR,C14-LGHT OF UPPER WEIR CREST,AG-AREA OF
C     ORIFICE,Y1-DEPTH OF WATER IN INTERCEPTOR,H-HGHT OF ORIFICE GATE,
C     Q2-AS ABOVE,Q5-FLOW DIVERTED TO INTERCEPTOR
C     C15-WIDTH OF ORIFICE
C     DETERMINE BRACKETTED EXPRESSIONS
C     WRITE(5,500)ND,Q,C1,C2,C3,C4    ,C6,C7,C8,C9,C10,C11,C12,C13,C14,
C    1H,Y1,C15,DF,HF
C 500 FORMAT(39H TYPES ND,Q,C1,C2,C3,C4,C6,C7,C8,C9,C10/I5,10F10.5
C    1/31H C11,C12,C13,C14,H,Y1,C15,DF,HF/9F10.5)
      BA=Q**2/(64.4*C3**2*C7**2)-5.
      BB=BA+5.-HF
C     IS THERE FLOW OVER FABRIDAM
      IF(BB)1,1,2
    1 BB=0.
      GO TO 3
    2 BB=1.
    3 IF(BA)4,4,9
    4 BA=0.
      GO TO 10
    9 BA=1.
   10 IF(BA+BB)5,5,11
   11 CONTINUE
      LF=TOP(DF,HF)
C     WRITE(5,501)LF,BA,BB
C 501 FORMAT(15H TYPES LF,BA,BB,3F10.5)
      QMAX=Q
      QMIN=0.
      K=1
    7 Q2=(QMAX+QMIN)/2.
      BC=Q2**2/(64.4*(C3*C7)**2)-5.
      BD=Q2**2/(64.4*(C3*C7)**2)-HF
      IF(BC)22,23,23
   22 BC=0.0000001
   23 IF(BD)24,25,25
   24 BD=0.0000001
   25 F=Q-Q2-C1*C2*BA*(BC)**1.5-C4*LF*BB*(BD)**C6
C     WRITE(5,502)Q2,F,K,BC,BD
C 502 FORMAT(13H TYPES Q2,F,K,2F10.5,I5,2F10.5)
      CALL BISECC(F,Q2,QMAX,QMIN,K,ND,QN)
      IF(K-50)7,8,8
C     2ND DIVERSION
    5 Q2=Q
    8 IF(Y1-C13-H/2.)12,12,13
   12 HS=H/2.
      GO TO 14
   13 HS=Y1-C13
C     IS THERE DISCHARGE OVER WEIRS
   14 AG=C15*H
      BA=1.
      BB=1.
      IF(Q2**2/(64.4*(C11*AG)**2)-C12+HS)15,15,16
   15 BA=0.
   16 IF(Q2**2/(64.4*(C11*AG)**2)-C8+HS)17,17,18
   17 BB=0.
      IF(BA+BB)18,19,18
   18 QMAX=Q2
      QMIN=0.
      K=1
C     WRITE(5,503)HS,AG,BA,BB
C 503 FORMAT(18H TYPE5 HS,AG,BA,BB,4F10.5)
   20 Q5=(QMAX+QMIN)/2.
      BC=Q5**2/(64.4*(C11*AG)**2)-C12+HS
      BD=Q5**2/(64.4*(C11*AG)**2)-C8 +HS
      IF(BC)26,27,27
   26 BC=0.0000001
   27 IF(BD)28,29,29
   28 BD=0.0000001
   29 F=Q2-Q5-C9*C10*BA*(BC)**1.5-C9*C14*BB*(BD)**1.5
C     WRITE(5,504)Q5,F,K
C 504 FORMAT(13H TYPE5 Q5,F,K,2F10.5,I5)
      CALL BISECC(F,Q5,QMAX,QMIN,K,ND,QN)
      IF(K-50)20,21,21
   19 Q5=Q2
   21 RETURN
      END

      SUBROUTINE TYPE6(ND,Q,QM)
C     RANDOLPH AND 31ST ST
C     THIS SUBROUTINE GIVES THE    DRY WEATHER FLOW AT THIS POINT WITH
C     NO ADDITION OF STORMWATER
      IF(Q.LE.QM)GO TO 2
      Q=QM
    2 RETURN
      END

      SUBROUTINE TYPE7(ND,Y,H,C1,C2,Q)
C     BY PASS FLOW AT METERS
C     NC-CACHMENT NO,Y-DEPTH OF FLOW AT DIVERSION,H-HGHT OF GATE OPENING
C     C1-COEFF OF DISCHARGE OF ORIFICE(GATE) C2-WIDTH OF ORIFICE
C     Q2-DISCHARGE TO INTERCEPTOR,Q-FLOW APPROACHING DIVERSION
      IF(Y-H/2.)1,1,2
    2 Q2=Q-C1*H*C2*SQRT(64.4*(Y-H/2.))
      Q=Q2
      RETURN
    1 WRITE(5,3) ND
    3 FORMAT(14H GATE TOO HIGH,I5)
      Q=0.0
      RETURN
      END
      FUNCTION AREA (D,YY)
      Y=YY
      IF(Y.GT.0.0001)GO TO 6
    9 AREA=0.000001
      RETURN
    6 CONTINUE
      IF((D/2.0)**2-(ABS(D/2.0-Y))*(ABS(D/2.0-Y)))14,14,15
   14 AREA=3.14159*D*D/4.0
      RETURN
   15 CONTINUE
      X=SQRT((D/2.)**2-(ABS(D/2.-Y))*(ABS(D/2.-Y)))
   20 IF(Y-D/2.)4,2,2
    4 TH=2.0*ATAN(X/(D/2.-Y))
      GO TO 3
    2 TH=2.0*ATAN((Y-D/2.)/X)+3.14159
    3 AREA=(TH-SIN(TH))*D*D/8.
      RETURN
      END

      SUBROUTINE BISECC(F,QZ,QMAX,QMIN,K,NC,QN)
C     ROUTINE CALCULATES NEW VALUE OF Q FOR SOLUTION BY METHOD OF
C     BISECTION,I.E. VALUE OF Q WHICH MAKES F=0
C     K-COUNTER,NC-CACHMENT NO,QN-PRESENT VALUE OF Q
C     AS Q INCREASES F MUST DECREASE.F MUST BE SINGLE VALUED
      IF(K-1)1,2,1
    1 IF(ABS((QN-QZ)/QZ)-0.10)3,2,2
    2 K=K+1
      QN=QZ
      IF(K-50)13,14,14
   13 IF(F)8,7,7
    7 QMIN=QZ
      RETURN
    8 QMAX=QZ
      RETURN
    3 K=50
      RETURN
   14 WRITE(5,15)NC
   15 FORMAT(27H NOT CONVERGING CACHMENT NO,I5)
      RETURN
      END

      FUNCTION TOP(D,Y)
      IF(4.0*(D*Y-Y*Y))1,2,2
C   1 WRITE(6,3)Y,D
    3 FORMAT(5X,5H Y,D ,2F10.2)
    1 Y=D
    2 CONTINUE
      TOP=SQRT(4.0*(D*Y-Y*Y))
C     TOP IS TOP WIDTH,D-DIAM,Y-DEPTH
      RETURN
      END

      FUNCTION CRES(D,H)
C     AREA OF CRESCENT
C     USES FUNCTION AREA
      H1=(D-H)/2.
      A=AREA(D,H1)
      CRES=(D/2.)**2*3.14159-2.*AREA(D,H1)
      RETURN
      END
      FUNCTION TRAPOZ(N,XINTL,J)
      REAL NAMES,LISTA,LISTB,LISTC,LISTD
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),NAMES(48),
     1LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,
     3QPP(15,120)
      SIMPSN=(QPP(J,1)+QPP(J,N))/2.0
      N1=N-1
      DO 2 I=2,N1
    2 SIMPSN=SIMPSN+QPP(J,I)
      TRAPOZ=SIMPSN*XINTL
      RETURN
      END


      SUBROUTINE   FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NP)
      DIMENSION   GATES(2),DF(19),NQ(19)
      COMMON/DIVE/DF,NQ
      DATA GATES(1),GATES(2)/5HGATES,4HETTG/
      LS=0
      CALL SEEK (7,GATES)
    4 READ(7,5) J,LH,LM,LD,HG,HF,HGMAX,HFMAX
      IF(J.NE.ND) GO TO 2
      CALL TMADD(LS,LM,LH,LD,0,-IMINH,-IHRH,-IDAYH)
      IF(LD.GE.0) GO TO 3
    2 HGG=HG
      HFF=HF
    5 FORMAT(I3,5X,2I3,I4,4F5.2)
      GO TO 4
    3 NP = LD*288+LH*12+LM/5
      CALL CLOSE (7)
      RETURN
      END


C*****CHAIN 5
C      PAL METHOD OF ROUTING
C      JR-CONSTANTS,ICONTB-OPERATION NO,ICONTC NO OF OPERATIONS
      REAL LISTA,LISTB,LISTC,LISTD,NAMES
      DIMENSION JR(48,7),QMAX(48),D(3),S(3),QPPDX(2),Q(120),TEMP(2),
     1QPP(15,120)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),
     1NAMES(48),LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,QPP
     3,ITIMES(12)
          COMMON/BLCK5/JR,Q,IJ,QMAX,JJ(120)
      COMMON/BKDI/D,S,AN,DF(19),DIVC(17,5),DIVCC(10)
      DATA QPPDX(1),QPPDX(2)/5HQPPDI,4HVERT/
      DATA TEMP(1),TEMP(2)/5HTEMPO,4HFILE/
      ICONTD=5
      IY=0
      DO 70 I=1,NDTT
   70 JJ(I)=-(NDTT-KK)+I
   80 CALL SEEK(8,LISTC)
      READ(8)JR,QMAX,D,S,AN,ICONTC,DF,DIVC,DIVCC
      CALL CLOSE(8)
      ICONTB=0
      CALL SEEK(8,QPPDX)
   60 READ(8)QPP
```

```
      CALL CLOSE(8)
    5 ICONTB=ICONTB+1
      IH=JR(ICONTB,2)
      IHH=JR(ICONTB,4)
      IJ=0
      IE=JR(ICONTB,1)
      GO TO(1,2,3,40),IE
    1 CALL ROUTB(IH,IHH)
      GO TO 4
    2 CONTINUE
      IHA=JR(ICONTB,3)
      CALL COMB(IH,IHA,IHH)
      GO TO 4
    3 CALL DIVIN(IH)
      GO TO 4
   40 DO 42 I=1,NDTT
   42 QPP(IH,I)=QPP(IH,I)+QMAX(ICONTB)
    4 CALL SENSE(14,IIB(15))
      IF(IIB(15).EQ.1)GO TO 6
      CALL SENSE(7,IIB(8))
      CALL SENSE(8,IIB(9))
      IF(IJ.EQ.0)GO TO 82
      CALL SENSE(1,IIB(2))
      IF(IIB(2).EQ.1)GO TO 82
      WRITE(5,12)NAMES(ICONTB)
   82 IF(IIB(8).EQ.0.AND.IIB(9).EQ.0)GO TO 41
      IF(IIB(8).EQ.1.AND.IJ.EQ.0.AND.IIB(9).EQ.0)GO TO 41
      WRITE(5,8)NAMES(ICONTB),IE,ICONTB,QMAX(ICONTB),MIHR,MIMIN,MIDAY
    8 FORMAT(//14H HYDROGRAPH AT2X,A5,5X,10H OPERATION I3,7H NUMBER I3,
     15X,5HQMAX ,F10.2,3X,11HTIME PT. 1 ,2I3,I4)
      WRITE(5,9)(JJ(IO),QPP(IHH,IO),IO=1,NDTT)
    9 FORMAT(1X,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,
     1I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1,I3,F7.1)
   12 FORMAT(/18H EXCESSIVE FLOW AT 2X,A5,2X,9H********** /
     146H BOB CALLERY'S BASEMENT WILL BE FLOODED*******    )
   41 CONTINUE
      IF(ICONTB-ICONTC)5,6,6
    6 CONTINUE
      CALL CHAIN (2)
      STOP
      END


      SUBROUTINE ROUTB(IH,IHH)
      REAL NAMES,LISTA,LISTB,LISTC,LISTD
      DIMENSION Q(120),JR(48,7),QMAX(48),QPP(15,120)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),
     1NAMES(48),LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,QPP
           COMMON/BLCK5/JR,Q,IJ,QMAX
       NRCHS=JR(ICONTB,7)
      LAG=JR(ICONTB,6)
      NSTRL=JR(ICONTB,5)
      DO 56 I=1,NDTT
      IF(QPP(IH,I).LT.QMAX(ICONTB))GO TO 56
      IY=1
      IJ=1
   56 CONTINUE
C     WRITE(5,40)ICONTB,(JR(ICONTB,I),I=1,7)
```

```
C   40 FORMAT(8I6)
        ANS=NSTRL
C     PERFORM  AVERAGING
        DO 20 IZ=1,NRCHS
        DO 7 IX=1,NDTT
        J=IX-NSTRL/2
        JX=J+NSTRL-1
        Q(IX)=0.0
        IF(J-1)2,3,3
      3 IF(JX-NDTT)4,4,5
      2 JJ=NSTRL-JX
        AJJ=JJ
        Q(IX)=AJJ*QPP(IH,1)
        J=1
        GO TO 4
      5 JL=JX-NDTT
        AJL=JL
        JX=NDTT
        Q(IX)=AJL*QPP(IH,NDTT)
      4 DO 1 IK=J,JX
      1 Q(IX)=Q(IX)+QPP(IH,IK)
      7 Q(IX)=Q(IX)/ANS
C       WRITE(5,45)ANS,Z,X,Y
C   45 FORMAT(10H ANS,Z,X,Y,4F10.5)
        IF(MOD(NSTRL,2).EQ.0.AND.MOD(IZ,2).EQ.0)GO TO 6
        DO 50 L=1,NDTT
     50 QPP(IH,L)=Q(L)
        GO TO 33
      6 DO 51 L=2,NDTT
     51 QPP(IH,L-1)=Q(L)
        QPP(IH,NDTT)=Q(NDTT)
     33 CONTINUE
     20 CONTINUE
        DO 32 I=1,NDTT
     32 Q(I)=QPP(IH,I)
     41 FORMAT(10F10.2)
C       PERFORM  LAGGING
        ICN=0
        IF(LAG)38,21,21
     21 IF(MOD(NSTRL,2).EQ.0)ICN=NRCHS/2
        GO TO 30
     38 CONTINUE
        NRCHS=1
     30 LAG=IABS(LAG)*NRCHS+ICN
        IF(LAG.GE.0)GO TO 44
        LL=NDTT+LAG
        DO 42 IN=1,LL
         INLAG=IN-LAG
     42 QPP(IHH,IN)=Q(INLAG)
        LL=LL+1
     43 QPP(IHH,IN)=Q(NDTT)
        RETURN
     44 LL=LAG+1
        DO 9 IN=LL,NDTT
          INLAG=IN-LAG
      9 QPP(IHH,IN)=Q(INLAG)
        DO 10 IN=1,LAG
     10 QPP(IHH,IN)=Q(1)
        RETURN
        END
      SUBROUTINE COMB(IH,IHA,IHH)
      REAL NAMES,LISTA,LISTB,LISTC,LISTD
      DIMENSION JR(48,7)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),
     1NAMES(48),LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,
     3QPP(15,120)
          COMMON/BLCKS/JR,Q(120),IJ,QMAX(48)
      DO 1 I=1,NDTT
    1 QPP(IHH,I)=QPP(IH,I)+QPP(IHA,I)
      RETURN
      END

      SUBROUTINE DIVIN(IH)
      REAL NAMES,LISTA,LISTB,LISTC,LISTD
      DIMENSION JR(48,7)
          COMMON/BLCKS/JR,Q(120),IJ,QMAX(48)
      COMMON DTT,NDTT,IDT,NTER,DT,IIB(18),LLOCI(15),
     1NAMES(48),LISTA(2),LISTB(2),LISTC(2),LISTD(2),KK,ICONTA,ICONTB,
     2ICONTC,ICONTD,IC,IY,MIHR,MIMIN,MIDAY,MISEC,RAIN(2),NG,NC,
     3QPP(15,120)
      COMMON/BKDI/D(3),S(3),AN,DF(19),DIVC(17,5),DIVCC(10)
      COMMON/TY/C1,C2,C3,C4,C5,X6,X7,X8,X9,X10,X11,X12
      IB=JR(ICONTB,7)
      IA=JR(ICONTB,6)
      ND=JR(ICONTB,5)
      C1=DIVC(ND,1)
      C2=DIVC(ND,2)
      C3=DIVC(ND,3)
      C4=DIVC(ND,4)
      C5=DIVC(ND,5)
      VOLA=TRAPOZ(NDTT,DTT,IH)
      NP2=0
      NPT=NDTT
      IDTM=IDT/60
      LSX=-(NDTT-KK-1)*IDT
      IS=0
      IMINH=MIMIN
      IHRH=MIHR
      IDAYH=MIDAY
      CALL TMADD(IS,IMINH,IHRH,IDAYH,LSX,0,0,0)
   14 CALL FABGTS(ND,IMINH,IHRH,IDAYH,HGG,HFF,NP)
      IF(NPT.LE.NP) GO TO 10
      NP1=NP2+1
      NP2=NP
      GO TO 11
   10 NP1=NP2+1
      NP2=NDTT
   11 DO 22 K=NP1,NP2
      GO TO (1,1,1,1,1,1,7),IA
    1 CALL TYPE1 (ND,DF(ND),HFF,HGG,QPP(IH,K),Q2,1)
      QPP(IH,K)=Q2
      GO TO 22
    7 IF(HGG.LE.0.1)GO TO 22
      CALL VALY(D(IB),Y,S(IB),QPP(IH,K),AN)
      CALL TYPE7(ND,Y,HGG,DIVC(ND,1),DIVC(ND,2),QPP(IH,K))
   22 CONTINUE
      IF(NP2.EQ.NDTT) GO TO 13
      NPT=NDTT-NP2
      NP=NP*IDTM+IDTM
      CALL TMADD(IS,IMINH,IHRH,IDAYH,C,NP,0,0)
      GO TO 14
   13 CONTINUE
      IF(IIB(7).EQ.0)GO TO 15
      VOLB=TRAPOZ(NDTT,DTT,IH)
      VOLC=VOLA-VOLB
      WRITE(5,16)VOLA,VOLB,VOLC
   16 FORMAT(24H VOLUME BEFORE DIVERSION,F10.0/
     122H VOLUME TO INTERCEPTOR,F10.0/
     216H VOLUME TO RIVER,F10.0)
   15 CONTINUE
      RETURN
      END


      SUBROUTINE VALY(D,Y,SO,QO,AN)
C     GIVEN D-DIAM,SO-BED SLOPE,QO-DISCH,AND-MANNINGS N, ROUTINE FINDS
C     NORMAL DEPTH-Y FOR CIRCULAR SECTION,USING BISECTION. AREA FUNCTION
C     USED.
      K=0
      YMIN=0.0
      YMAX=D
    8 Y=(YMIN+YMAX)/2.0
      K=K+1
   10 FORMAT(21H NORMAL DEPTH USED AS,F10.3,34H   DISCHARGE IS.GT.SECTI
     1ON CARRY         )
      IF(K.LE.10)GO TO 12
   11 Y=0.94*D
      WRITE(5,10)Y
      GO TO 4
   12 A=AREA(D,Y)
      V=QO/A
      IF(Y-D/2.)1,1,2
    1 Q=1.0
      GO TO 3
    2 Q=-1.0
    3 P=5.0
      R=A/P
      S=AN*AN*V**2/(2.22*R**1.333)
      IF(ABS(S-SO).LT.0.0001)GO TO 4
    5 IF(S-SO)6,4,7
    6 YMAX=Y
      GO TO 8
    7 YMIN=Y
      GO TO 8
    4 RETURN
      END
```

BIBLIOGRAPHIC:

Minneapolis-Saint Paul Sanitary District, Dispatching System For Control of Combined Sewer Losses, Final Report FWQA Grant No. 11020 FAQ, March, 1971.

ABSTRACT

Impressive reductions in combined sewer overflow pollution of the Mississippi River in Minneapolis and Saint Paul have been effected by a regulator control system. Working entirely within the limits of the existing interceptor sewer system, and with relatively minor modifications to selected major combined sewer regulators, incidence of overflow was reduced by 66% and duration of overflow by 88% during most of a rainfall season. Computer simulation techniques using actual rainfall data indicate that the amount of overflow volume reduction achieved is the equivalent of a $200 million separation project. The efficiency of collection was improved by about 20% at controlled regulators. The reduction in volume of combined overflow to the river is estimated to be between 35% and 70% during the runoff season. The unmodified combined sewer system captured about 65% of the urban runoff. Where modified, the system captured about 77% of the urban runoff.

ACCESSION NO.

KEY WORDS:

Combined Sewer
Regulator
Interceptor
Overflow
Control and Monitoring
Variable Diversion
Real Time Operation
Urban Hydrology
Stormwater Runoff

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The 1.75 million dollar project includes a computer-based data acquisition and control system that permits remote control of modified combined sewage regulators. Data from rain gages, regulator control devices, trunk sewers and interceptors, and river quality monitors provide real-time operating information. Time varient quality data from key locations in the sewer system were obtained by automated analysis of numerous hourly samples.

Work on the "Dispatching System for Control of Combined Sewer Losses" began in 1966, and the system has been operated since April, 1969.

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10 *Author(s)*
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27 *Abstract*

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